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THE ELECTRONIC THEORY OF ELECTRICITY.

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CONSIDERABLE progress has been made of late years in our knowledge concerning the structure and relations of atoms and electricity. Recent discoveries have moreover placed in a new light old theories and experimental work. The remarkable investigations and deductions made from his own experiments and those of others, which have led Professor J. J. Thomson to the conclusion that atoms can be split up into, or can give off, smaller masses, which he calls corpuscles, were explained by him in a most interesting article in the POPULAR SCIENCE MONTHLY for August, 1901.* There seems to be good evidence that in a glass vessel exhausted to a high vacuum through the walls of which are sealed platinum wires, we have a torrent of small bodies or so-called corpuscles projected from the kathode or negative wire, when the terminals are connected to an induction coil or electrical machine.

Twenty-five years ago Sir William Crookes explored with wonderful skill many of the effects due to electric discharge through such high vacua, and came to the conclusion that they could only be explained by the supposition that there was present in the tube matter in a *fourth state,* neither solid, liquid, nor gaseous, but 'radiant matter' projected in straight lines from the surface of the negative pole or kathode, the particles moving with immense velocity, and all charged

* See POPULAR SCIENCE MONTHLY, Vol. LIX., p. 323, 'On Bodies Smaller than Atoms,' by Professor J. J. Thomson, F.R.S. See also by the same author a paper in the *Philosophical Magazine* for December, 1899, 'On the Masses of the Ions in Gases at Low Pressures.'

with negative electricity. He showed by beautiful experiments that this radiant matter bombarded the glass walls and produced phosphorescence, could be focused on to metal sheets and render them red hot, and could drive round little windmills or vanes included in the tube. It therefore possesses the quality of inertia and in virtue of the electric charge it carries, it is virtually an electric current and can be deflected by a magnet. The proof which has been given by Professor Thomson that this 'radiant matter' consists of corpuscles, a thousand times smaller than an atom of hydrogen in mass, and that they are shot off from the kathode with a velocity which is comparable with that of light, explains at once both their kinetic energy and also the manner in which they are able to pass through windows of aluminium, as shown by Lenard, and get into the space outside the tube. Furthermore, evidence has been put forward to show that the electric charge carried by each one of these tiny corpuscles is exactly the same as that which a hydrogen atom carries in the act of electrolysis or when it forms a hydrogen ion.

It seems tolerably clear from all the facts of electrolysis that electricity can only pass through a conducting liquid or electrolyte by being carried on atoms or groups of atoms which are called *ions—i. e., wanderers.* The quantity thus carried by a hydrogen atom or other monad element, such as sodium, silver or potassium, is a definite natural unit of electricity. The quantity carried by any other atom or group of atoms acting as an ion is always an exact integer multiple of this natural unit. This small indivisible quantity of electricity has been called by Dr. Johnstone Stoney an *Electron* or *atom of electricity.* The artificial or conventional unit of electric quantity on the centimeter, gram, second system as defined by the British Association Committee on Electrical Units is as follows:

An *electrostatic unit* of electric quantity is the charge which when placed upon a very small sphere repels another similarly charged sphere, the centers being one centimeter apart, with a mechanical force of one dyne. The *dyne* is a mechanical unit of force and is that force which acting for one second on a mass of one gram gives it a velocity of one centimeter per second. Hence, by the law of inverse squares the force in dynes exerted by two equal charges Q at a distance D is equal to Q^2/D^2. Two other units of electric quantity are in use. The *electromagnetic unit,* which is thirty thousand million times as great as the electrostatic unit, and the *practical unit* called the coulomb or ampère-second which is three thousand million times the electrostatic unit. We can calculate easily the relation between the *electron* and the *coulomb;* that is, between *nature's unit* of electricity and the British Association unit, as follows:

If we electrolyze any electrolyte, say acidified water which yields

up hydrogen at the negative electrode, we find that to evolve a volume of one cubic centimeter of hydrogen gas at 0° C. and 760 mm. we have to pass through the electrolyte a quantity of electricity equal to 8.62 coulombs. For 96,540 coulombs are required to evolve one gram of hydrogen and 11,200 cubic centimeters at 0° C. and atmospheric pressure weigh one gram. The number 8.62 is the quotient of 96,540 by 11,200.

Various arguments, some derived from the kinetic theory of gases, indicate that the number of molecules of hydrogen in a cubic centimeter is probably best represented by the number twenty million million million $=2\times10^{19}$. Hence it follows, since there are two atoms of hydrogen in a molecule, that in electrostatic units the electric charge on a hydrogen atom or hydrogen ion is

$$\frac{96540\times3\times10^{9}}{11200\times4\times10^{19}}=\frac{65}{10^{11}}\text{ of a C. G. S. electrostatic unit}$$

$$=\frac{22}{10^{20}}\text{ of a coulomb.}$$

Accordingly, if the above atomic charge is called *one electron* then the conventional British Association electrostatic unit of electric quantity is equal to 1540 million electrons, and the quantity called a coulomb is nearly five million million million electrons. The electron or the electric charge carried by a hydrogen atom or ion is evidently a very important physical constant. If we electrolyze, that is decompose by electricity aqueous solutions of various salts, such as sodium chloride, zinc chloride, copper sulphate, silver nitrate, we find, in accordance with Faraday's Laws of Electrolysis, that the passage of a given quantity of electricity through these solutions decomposes them in proportional amounts such that for every 46 grams of sodium liberated there are 65 of zinc, 63.5 of copper and 216 of silver. These masses are called chemical equivalents. Accordingly, if we imagine a number of vessels placed in a row containing these solutions and by means of platinum connecting links or plates we pass an electric current through the series, for every atom of copper or zinc carried to their respective kathodes, we shall have two atoms of silver or sodium similarly transported. Since the same quantity of electricity must pass through every vessel in the same time it is evident that the above fact may be interpreted by assuming that whilst an atom of silver or sodium acting as an ion carries one electron, an atom of zinc or copper carries two electrons.

In the same way we may have atoms which carry three, four, five or six electrons. Thus we may interpret the facts of chemical valency and Faraday's Law of Electrolysis in terms of the electron.

We are thus confronted by the idea, long ago suggested by Weber and by Helmholtz, that the agency we call electricity is *atomic in structure,* that is to say, we can only have it in amounts which are all exact multiples of a certain small unit. Electricity therefore resembles those articles of commerce like cigars, which we can buy in exact numbers, 1, 10, 50, 100, 1000, but we cannot buy half a cigar or five sixths of a cigar. If then the law which holds good for electricity in association with atoms during electrolysis holds good generally, a very important advance has been made in establishing the fact that there is a small indivisible unit of it which can be multiplied but not divided, and every quantity of electricity, small or large, is an exact integer multiple of this unit, *the electron.*

Theories of Electricity.

Various answers have been given at different times to the question —What is electricity? It has been defined as an imponderable fluid, as a force, as a mode of motion, a form of energy, an ether strain or displacement or a molecular motion.

At one time physicists have considered it as a single entity or fluid; at others it has been pronounced to be duplex in nature and positive and negative fluids or electricities have been hypothecated.

The state of electrification has been looked upon at one period as due to an excess or defect of a single electricity, at others as a consequence of the resolution of some neutral fluid into two components. An electrical charge on a conductor has been regarded as something given to or put upon the conductor and also as a state of strain or displacement in the surrounding non-conductor. The intelligent but non-scientific inquirer is often disappointed when he finds no simple, and as he thinks essential, answer forthcoming to the above question, and he asks why it cannot be furnished.

We must bear in mind, however, that scientific hypotheses as to the underlying causes of phenomena are subject to the law of evolution and have their birth, maturity and decay. Theory necessarily succeeds theory, and whilst no one hypothesis can be looked upon as expressing the whole truth, neither is any likely to be destitute of all truth if it sufficiently reconciles a large number of observed facts.

The notion that we can reach an absolutely exact and ultimate explanation of any group of physical effects is a fallacious idea. We must ever be content with the best attainable sufficient hypothesis that can at any time be framed to include the whole of the observations under our notice. Hence the question, What is electricity? no more admits of a complete and final answer to-day than does the question, What is Life? Though this idea may seem discouraging, it does not follow that the trend of scientific thought is not in the right

direction. We are not simply wandering round and round, chasing some elusive Will-o'-the-wisp, in our pursuit after a comprehension of the structure of the universe. Each physical hypothesis serves, however, as a lamp to conduct us a certain stage on the journey. It illuminates a limited portion of the path, throwing a light before and behind for some distance, but it has to be discarded and exchanged at intervals because it has become exhausted and its work is done.

The construction and testing of scientific theories is therefore an important part of scientific work. The mere collection of facts or even their utilization is not the ultimate and highest goal of scientific investigation. The aim of the most philosophic workers has always been to penetrate beneath the surface of phenomena and discover those great underlying fundamental principles on which the fabric of nature rests. From time to time a fresh endeavor has to be made to reconstruct, in the light of newly acquired knowledge, our scientific theory of any group of effects. Thus, the whole of electrical phenomena have become illuminated of late years by a theory which has been developed concerning the atomic structure of electricity and this hypothesis is called the Electronic Theory of Electricity.

The Atomic Theory.

The opinion that matter is atomic in structure is one which has grown in strength as chemical and physical knowledge has progressed. From Democritus, who is said to have taught it in Greece, to John Dalton who gave it definiteness, and to Lord Kelvin who furnished the earliest numerical estimate of the size of atoms, it has been found to be the best reconciler of very diverse and numerous facts. Let us consider what it really means. Suppose we take some familiar substance, such as common table salt, and divide a mass of it into the smallest grains visible to the eye. Each tiny fragment is as much entitled by all tests to be called table *salt,* or to give it the chemical name, sodic chloride, as a mountain of the material. Imagine that we continue the subdivision under a good microscope; we might finally obtain a little mass of about one hundred-thousandth of an inch in diameter, but beyond this point it would hardly be visible even under a powerful lens. We may, however, suppose the subdivision continued a hundred fold by some more delicate means until we finally arrive at a small mass of about one ten-millionth of an inch in diameter. A variety of arguments furnished by Maxwell, Boltzmann, Loschmidt, Lord Kelvin and others show that there is a high degree of probability that any further subdivision would cause the portions into which the salt is divided to be no longer identical in properties, but there would be two kinds of parts or particles, such that if all of one kind were collected together they would form a metal called sodium, and if all

of the other kind were similarly picked out they would form a non-metal called chlorine. Each of these smallest portions of table salt, which if divided are no longer salt, is called a *molecule* of sodic chloride, and each of the parts into which the molecule is divisible is called an *atom,* of sodium or of chlorine. In dealing with the dimensions of these very small portions of matter an inch or a centimeter is too clumsy a unit. To express the size of an atom in fractions of an inch is worse than stating the diameter of an apple in fractions of a mile. Every one knows what is meant by a millimeter; it is nearly one twenty-fifth part of an inch. A meter is equal to a thousand millimeters. Suppose a millimeter divided into a thousand parts. Each of these is called a *micron* and denoted by the Greek letter . This however is still too large a unit of length for measuring the size of atoms, so we again divide the micron into a thousand parts and call each a micromillimeter or *micromil,* and denote it by the symbol $\mu\mu$. Lord Kelvin's estimate of the diameter of a molecule is that it lies between one hundredth of a micromil and two micromils, that is between .01 $\mu\mu$ and 2 $\mu\mu$. This is certainly a very wide estimate, but it is the best yet to hand, and for present purposes we may take it that an atom is a small portion of matter of approximately one millionth of a millimeter or one micromil (1 $\mu\mu$) in diameter. On the same scale the wave length of a ray of yellow light is about 0.6 μ or 600 $\mu\mu$. that is six hundred times the size of an atom. We know nothing as yet about the relative sizes of different kinds of atoms. In the next place as regards the number of molecules in a given space, various distinguished physicists, Maxwell, Kelvin, Boltzmann, Van der Waals and others, have given estimates for the number of molecules in a cubic centimeter of air at ordinary temperature and pressure, which vary between 10^{18} and 10^{21} or between a million billion and a thousand million billion. All we can do is to take a rough mean of these different values, and we shall consider that in one cubic centimeter of hydrogen or other gas at 0° C. and 760 mm. or freezing point and ordinary pressure there are about 2×10^{19} or twenty million million million molecules. To understand what this enormous number means we must realize that if we could pick out all the molecules in one cubic inch of air and place them side by side in a row, small as they are individually, the row would extend nearly twice the distance from the earth to the sun.

Having provided ourselves with a rough idea of the sizes and numbers of the molecules of any gas we proceed to obtain an idea of their weight or mass. Since 11,162 cubic centimeters of hydrogen gas at 0° C. and 760 mm. weigh one gram, it follows from the above facts that each molecule of hydrogen has a mass of nearly $1/10^{23}$ of a gram. To weigh these tiny atoms we must therefore take a

unit of weight equal to one billionth of one billionth of a gram, and then on this scale the hydrogen molecule weighs 10 such units. We may obtain in another way an illustration of the mass size and number of the molecules of any gas in the following manner:

First as to size. We can in a good Whitworth measuring instrument detect a variation in length of a metal bar equal to one millionth of an inch. This short length would be occupied by 25 molecules placed in a row close together. We can in a good microscope see a small object whose diameter is one hundred-thousandth of an inch. In a small box of this size we could pack 16 million molecules close together. The smallest weight which can be weighed on a very good chemical balance is one hundredth of a milligram. The united weight of one million million million molecules of hydrogen would therefore just be detectable on such a balance.

Ultra-Atomic Matter.

Until a few years ago our knowledge of the divisibility of matter may be said to have ended with the chemical unit, the atom. But of late years information has been steadily accumulating which has made us acquainted with matter in a finer state of subdivision. For a long time a controversy was carried on, whether the radiation in a high vacuum tube which proceeds from the kathode was a material substance or a wave motion of some kind. But no fact yet found is inconsistent with the notion which originated with Sir William Crookes that the transfer which takes place is that of something which has the inertia quality of matter, and his term 'radiant matter' is a peculiarly suitable phrase to describe the phenomena. The great advance which has since been made, by Professor Thomson and others, is that of measuring accurately the amount of bending which a stream of this radiant matter experiences under a known magnetic force and from this deducing the ratio between the mass of the radiant particle and the electric charge carried by it. This measurement shows that if the radiant matter consists of corpuscles or particles, each of them carries a charge of one electron, but has a mass of about one thousandth of a hydrogen atom.

The evidence therefore exists that Crookes' 'radiant matter' also called the 'kathode rays' and Thomson's 'corpuscles' are one and the same thing and that these corpuscles may be described as fragments broken off from chemical atoms and possessing only a small fraction of their mass. These particles are shot off from the negative terminal or kathode of the vacuum tube with a velocity which is from one fifth to one third the velocity of light.

Moreover it has been shown that when the kathode rays pass through a thin metal window in a vacuum tube and get into the space

outside, thus forming Lenard's rays, they are likewise only the same or similar corpuscles in the space outside rather than inside the vacuum tube. Finally it has been proved that these electrified corpuscles are present as well in the mass of a gas through which Röntgen rays have passed, also in the mysterious radiation called Becquerel rays which proceeds from uranium and other radio-active substances, also in all flames, near all very hot bodies and in the air near certain metallic surfaces on which ultra-violet light falls. In every case the corpuscle is charged with an electron charge of negative electricity. If a corpuscle originates as a fragment chipped off from an electrically neutral atom and is negatively charged, it follows that the remainder of the atom of matter is left positively charged.

The word 'atom' therefore, as far as it signifies something which *cannot be cut,* is becoming a misnomer as applied to the chemical unit of matter, because this latter is capable of being divided into two parts of very unequal size. First, a small part which is negatively electrified and which is identically the same, no matter from what chemical atom it originates, and secondly, a much larger mass which is the remainder of the atom and is positively electrified, but which has a different nature depending on the kind of chemical atom broken up. The question has then begun to be debated whether we can distinguish between the corpuscle and the electric charge it carries and if so in what way. In other words, can we have an unelectrified corpuscle or is the corpuscle so identified with its electric charge that they are one and the same thing? It has been shown experimentally that an electric charge in motion is in effect an electric current, and we know that an electric current possesses something equivalent to inertia, that is, it cannot be started and stopped instantly, and it possesses energy. We call this electric inertia *inductance,* hence the question arises whether the energy of the corpuscles when in motion is solely due to the electric inductance or whether it is partly due to what may be called the ponderable inertia of the corpuscle.

This very difficult question has not yet been even approximately settled. At the present moment we have no evidence that we can separate the electron charge from the corpuscle itself. If this is the case, then the corpuscles taken together constitute for all practical purposes negative electricity, and we can no more have anything which can be called electricity apart from corpuscles than we can have momentum apart from moving matter. For this reason it is sometimes usual to speak of the corpuscle carrying its charge of one electron of negative electricity simply as *an electron,* and to drop all distinction between the electric charge and the vehicle in or on which it is conveyed.

It is remarkable that so far no one has been able to produce or find a corpuscle positively electrified. Positive electricity is only known in

association with masses as large as atoms, but negative electricity is identified with corpuscles or masses only a small fraction of the size of an atom. This does not prove that an atom may not include positive corpuscles or electrons, but only that so far we have not been able to isolate them.

The Electronic Theory of Electricity.

From this point of view a theory of electricity originates called the electronic theory. The principal objects of consideration in this theory are these electrons which constitute what we call electricity. An atom of matter in its neutral condition has been assumed to consist of an outer shell or envelope of negative electrons associated with some core or matrix which has an opposite electrical quality, such that if an electron is withdrawn from the atom the latter is left positively electrified.

A neutral atom *minus* an electron constitutes the natural unit of positive electricity and the electron and the neutral atom minus an electron are sometimes called negative and positive ions. Deferring for a moment a further analysis of possible atomic structure we may say that with the above hypothesis in hand we have then to express our statements of electrical facts in terms of the electron as the fundamental idea.

All that can be attempted here is a very brief exposition of the success which has so far attended this effort to create a new range of electrical conceptions. Let us consider first the fundamental difference between substances in respect of electrical conductivity. In the electronic theory what is the distinction between conductors and non-conductors? It must be remembered that on the electronic hypothesis an electric current is a movement of electrons. Hence a conductor must be a substance in which electrons free to move exist. It is considered therefore that in metals and good conductors a certain proportion of the atoms are broken up into positive and negative ions or into electrons and remainders of atoms which we may call coelectrons. There may be a constant decomposition and recomposition of atoms taking place, and any given electron so to speak flits about, now forming part of one atom and now of another and anon enjoying a free existence. It resembles a person visiting from house to house forming a unit in different households and in between being a solitary person in the street. In non-conductors on the other hand the electrons are much restricted in their movements, and can be displaced a little way but are pulled back again when released. The positive and negative ions or electrons and coelectrons never have the opportunity to part company very far.

The reader who is familiar with the modern doctrine of the ionization of salts in solution will see that a close similarity exists between this view of the atomic state of a metal and the chemical state of a salt in solution. The ionic theory of solution is that if some salt, say

sodic chloride, is placed in water a certain proportion of the molecules of sodic chloride are dissociated into sodium and chlorine ions, that is to say, atoms possessing electric charges, and the electric conductivity of the solution is due to the mobility of these saline ions.

On the electronic theory a certain proportion of the atoms of a conductor are similarly in a state of electronization. The application of an electromotive force to the conductor thus at once causes the electrons to begin to migrate. If we compare conductors and non-conductors we shall see that the former are mostly elementary bodies, the metals and alloys or graphitic carbon, whilst the latter are all very complex substances such as glass, ebonite, the oils, shellac, gutta-percha, etc. These last have large and complex molecules but the good conductors have all simple molecules and small atomic volumes. The exceptions apparently are sulphur and carbon in the form of diamond. When, however, we remember that carbon and sulphur are elements very prone to polymerize and so to speak combine with themselves they may not really be an exception. The electrons may therefore have much more difficulty in exchanging from atom to atom or in making their way between or through the molecules when these are very complex than when they are simple.

The question then may be asked why these free electrons do not all escape from the conductor. The answer is that there must be an equal quantity of electrons and coelectrons or remainders of atoms or of so-called negative and positive ions, and the stronger attraction between these involves the expenditure of work to separate them. The radio-active substances, such as uranium, polonium, radium, actinium and others, to which so much attention has been paid lately, do seem to have the power of emitting their corpuscles or electrons and scattering them abroad, and hence can only do this at the expense of some of their own internal molecular energy or else drawing upon the heat of surrounding bodies.

We come next to the explanation of the familiar fact of electrification by friction. Why is it that when we rub a glass rod with a bit of silk the two things are equally and oppositely electrified? To explain this on the electronic theory we have to consider the state of affairs at the surface of any substance immersed say in air. At the surface where the air and glass meet there will be an electronization of atoms which appears to result in the formation of a double layer of electrons and coelectrons or negative and positive ions. This is probably an attempt on the part of the glass and air to combine chemically together. The same state exists at the surface of the silk. When we rub these two things together these double layers are very roughly treated and are broken up. The whole lot of electrons and coelectrons or residual portions of atoms get mixed up and more or less divided up between the

two surfaces. As however every negative electron has its positive coelectron, it follows that what one surface gains the other must lose. Hence in the end we may have a majority of negative ions or electrons left on the one surface and a majority of positive ions or coelectrons left on the other surface, and the glass and the silk are then electrified with equal quantities but opposite sign. Owing to the mutual repulsion of the similar electrons the charge resides wholly on the surface.

This conception of the existence of a double layer of opposite electricities or ions at the surface of contact of two substances has been put forward to account for the familiar effect of the electrification of air by falling drops of water. It has long been known that the air in the neighborhood of waterfalls of fresh water is electrified negatively, whereas the air in the neighborhood of splashing salt water, as at the seaside, is positively electrified and the explanation that has been given by Professor J. J. Thomson is that this is due to the breaking up of this double layer of ions at the surface of the drop when it strikes the ground.

Atomic Valency.

At this stage it may be well to indicate that any valid theory of electricity must involve an explanation of the facts of chemical combination and chemical valency as well. At present all ideas on the structure of atoms must necessarily be purely speculative. So much advance has been made however in the development of a department of chemistry called stereo-chemistry that we need not despair of coming to know in time much about the architecture of atoms and molecules. The way is cleared, however, for some consistent explanations if we can assume that one or more free electrons can attach themselves to a neutral atom and so give it a negative charge of electricity. We may suppose as a first assumption that in a neutral atom which is otherwise complete there exist localities at which one or more electrons can find a permanent attachment. The atom is then no longer neutral but negatively electrified. If the atom can as it were accommodate *one* electron it is a monovalent element, if *two* it is divalent and so on. If it cannot accommodate any at all it is an *avalent* or *non-valent* element.

Consider the case of gaseous molecules. Chemical facts teach us that the molecules of free gaseous hydrogen, oxygen or other gases contain two atoms, so that these free molecules are represented by the symbols H_2, O_2, etc. In these cases hydrogen and oxygen are so to speak combined with themselves. We can explain this by the supposition that most neutral atoms are unstable structures. In contact with each other some lose one or more electrons and an equal number gain one or more electrons. Hence in a mass say of hydrogen we have some atoms which are positively electrified and some which are negatively electrified then called atomic ions, and these ions united pair and pair

form the molecules of hydrogen which may be represented by $(\overset{+}{H}, \overset{-}{H})$ similarly for other gases. Certain neutral atoms such as those of argon are monatomic and non-valent and these appear to be unable to enter into combination either with each other or with other atoms. Accordingly, in a mass of free hydrogen there are no free electrons and all the positively charged and negatively charged H atoms are in union. Hence the gas is a non-conductor of electricity. But we can make it a conductor by heating it to a high temperature. The explanation of this is that a high temperature dissociates some of the molecules into atoms and these under the action of electric force move in opposite directions, thus creating an electric current. Thus air at ordinary temperatures is an almost perfect non-conductor, but at a white heat it conducts electricity freely.

The monovalent elements like hydrogen are those neutral atomic structures which can lose one electron or take up one electron, becoming respectively positive atomic ions and negative atomic ions. In the same way the divalent elements such as oxygen are those neutral atomic structures which can part with two electrons and take up two and so on for trivalent, quadrivalent, etc., atoms. The work required to remove the second electron probably is very much greater than that required to remove the first. Hence in polyvalent atoms the valencies have unequal energy values.

Consider now a mass of intermingled oxygen and hydrogen consisting of neutral molecules. The state is a stable one as long as all the molecules are neutral. If, however, we dissociate a few of the hydrogen and oxygen molecules by an electric spark or by heat then there is a recombination. A positive oxygen ion unites with two negative hydrogen ions and a negative oxygen ion with two positive hydrogen ions and the result is two neutral molecules of water. This combination takes place because the union of oxygen ions with hydrogen ions to form water evolves more heat and exhausts more potential energy than the combination of oxygen with oxygen and hydrogen with hydrogen ions in equivalent quantity. The energy set free by the union of the O and H is sufficient to continue the dissociation of further gaseous molecules so the action is explosive and is propagated throughout the mass.

There is however a broad distinction between the elements in this respect, viz.: that some atoms are prevalently electropositive and others electronegative. A metallic atom for instance is electropositive, but the atoms of non-metals are mostly electronegative. Moreover metals in the mass are electrically good conductors, whereas non-metals in the mass are non-conductors or bad conductors. This may be explained by the varying degree of force required to detach electrons from neutral atoms and conversely the varying degree of attachment of electrons

for neutral atoms. Thus we may consider that the metallic atoms lose very easily one or more electrons and also that there is a somewhat feeble attachment in their case between the neutral atom and the free electron. Hence metals in the mass are conductors because there are plenty of free electrons present in them. On the other hand, in the case of non-metallic atoms the force required to detach one or more electrons from the atom is much greater and conversely the attachment of free electrons for the neutral atom is larger. Accordingly, in non-metals there are few free electrons and they are therefore non-conductors. Moreover the presence of positive and negative atomic ions causes them to link together into more or less complex molecules and they exhibit polyvalency and act as the grouping elements in molecular complexes. This is a very characteristic quality of the elements, sulphur, silicon and carbon.

Helmholtz long ago laid stress on the fact that certain physical and chemical effects could only be explained by assuming a varying attraction of electricity for matter. The same idea followed out leads to an hypothesis of chemical combination and dissociation of salts in solution. Thus a molecule of sodic chloride is the electrical union of a monovalent sodium ion or sodium atom *minus* one electron with a chlorine ion which is a chlorine atom *plus* one electron. It may be asked why in this case does not the extra electron pass over from the chlorine to the sodium ion and leave two neutral atoms. The answer is because the union between the electron and the chloride is probably far more intimate than that between the atomic groups. These latter may revolve round their common center of mass like a double star, but the electron which gives rise to the binding attraction may be more intimately attached to the atomic group into which it has penetrated.

Voltaic Action.

Any theory of electricity must in addition present some adequate account of such fundamental facts as voltaic action and magneto-electric induction. Let us briefly consider the former. Suppose a strip of copper attached to one of zinc and the compound bar immersed in water to which a little hydrochloric acid has been added.

All chemical knowledge seems to point to the necessity and indeed validity of the assumption that the *work* required to be done to remove an electron from a neutral atom varies with the atom. Conversely the attraction which exists between a free electron and an atom deprived of an electron also varies. Accordingly the attraction between atomic ions, that is, atoms one of which has gained and one of which has lost electrons, is different. Upon this specific attraction of an atomic ion for electrons or their relative desire to form themselves into neutral molecules depends what used to be called chemical affinity. Mr. Ruther-

ford has shown that negative ions gave up their charges more readily to some metals than others and most readily to the electro-positive metals. Hence a zinc atomic ion is more ready to take up electrons and again become neutral than a copper ion.

Consider then the simple voltaic couple above described. In the electrolyte we have hydrogen ions which are *H* atoms *minus* an electron, and chlorine ions which are chlorine atoms *plus* an electron. These are wandering about in a menstruum which consists of water molecules and hydrochloride acid molecules. Then in the metal bar we have zinc and copper divalent ions which are these atoms each minus two electrons, and also an equivalent number of free and mobile electrons.

If we adopt Volta's original view of contact electricity, we must assume that at the surface of contact of the metals there is some action which drives electrons across the boundary from the zinc to the copper. This may be due to the neutral copper atoms having a slightly greater attraction for electrons than the neutral zinc atom. The zinc is therefore slightly electrified positively and the copper negatively. Accordingly in the electrolyte the negative chlorine ions move to the zinc and combine with positive zinc ions, forming neutral zinc chloride, two chlorine ions going to one zinc ion. The hydrogen ions therefore diffuse to the copper side and each takes up a free electron from the copper, becoming neutral hydrogen atoms and there escape.

In proportion as the zinc atomic ions are removed from the zinc bar and the corresponding free electrons from the copper, so must there be a gradual diffusion of electrons from the zinc bar to the copper bar across the metallic junction. But this constitutes the voltaic current flowing in the circuit. It is a current of negative electricity flowing from zinc to copper and equivalent to a positive current from copper to zinc. The energy of this current arises from the differential attraction of zinc and copper ions for chlorine ions and is therefore the equivalent of the exhaustion of the chemical potential energy of the cell. Thus the electronic theory outlines for us in a simple manner the meaning of voltaic action. Even if we do not admit the existence of a metallic junction volta contact force, the theory of the cell may be based on the view that the movement of the saline ions in the electrolyte is determined by the law that that motion takes place which results in the greatest exhaustion of potential energy. Hence the chlorine ions move to the zinc and not to the copper.

In the same manner the electronic theory supplies a clue to the explanation of the production of an electric current when a conductor is moved across a magnetic field. Every electron in motion creates a magnetic force. Hence a uniform magnetic field may be considered as if due to a moving sheet of electrons. The 'cutting' of a conductor

across a magnetic field will therefore be accompanied by the same reactions as if a procession of electrons were suddenly started in it. This, however, would involve at the moment of starting a backward push on surrounding electrons, just as when a boat is set in motion by oars the boat is pushed forward and the water is pushed back. Hence there is an induced current at the moment when the field begins in the conductor. Similarly the reaction at stopping the procession would drag the surrounding electrons with it. Accordingly the induced currents when the field ceases is in the opposite direction to that when it begins.

The electronic theory has in the hands of other theorists such as Professors P. Drude and E. Riecke been shown to be capable of rendering an account of most thermomagnetic effects on metals, contact electricity, the so-called Thomson effects in thermoelectricity, and also the Hall effect in metals when placed in a magnetic field.

Electrons and Æther.

The ultimate nature of an electron and its relation to the æther has engaged the attention of many physicists, but we may refer here more particularly to the views of Dr. J. Larmor whose investigations in this difficult subject are described in his book on 'Æther and Matter' and also in a series of important papers on the transactions of the Royal Society of London, entitled 'A Dynamical Theory of the Electric and Luminiferous Medium' (*Phil. Trans. Roy. Soc.*, 1893, 1895, 1898). Larmor starts with the assumption of an æther which is a frictionless fluid, but possesses the property of inertia; in other words he assumes that its various parts can have motion with respect to each other and that this motion involves the association of energy with the medium. He regards the electron as a strain center in the æther, that is as a locality from which æther strain radiates. Electrons can therefore be either positive or negative according to the direction of the strain and to every positive electron there is a corresponding negative one. Atoms according to him are collocations of electrons in stable orbital motion like star clusters or systems.

An electron in motion is in fact a shifting center of æther strain and it can be displaced through a stationary æther just as a kink or knot in a rope can be changed from place to place on the rope.

An electron in vibration creates an æther wave but it radiates only when its velocity is being accelerated and not when it is uniform.

The type of æther which Larmor assumes as the basis of his reasoning is one which has a rotational elasticity, that is to say, the various portions of it do not resist being sheared or slid over each other, but they resist being given a rotation round any axis. Starting from these postulates and guided by the general and fundamental principle of Least

Action he has erected a consistent scheme of molecular physics in which he finds an explanation of most observed facts.

The discovery by Zeeman of the effect of a strong magnetic field in triplicating or multiplicating the lines in the spectrum of a flame placed in a magnetic field meets with an obvious explanation when we remember that the effect of a magnetic field on an electron in motion is to accelerate it always transversely to its own motion and the direction of the field. Hence it follows that a magnetic field properly situated will increase the velocity of an electron rotating in one direction and retard it if rotating in another. But a linear vibration may be resolved into the sum of two oppositely directed circular motions and accordingly a magnetic force properly applied must act on a single spectral line, which results from the vibration of an electron in such manner as to create two other lines on either side, one representing a slightly quicker and the other a slightly slower vibration.

The notion of an electron or point charge of electricity as the ultimate element in the structure of matter having been accepted, we are started on a further enquiry as to the nature of the electron itself. It is obvious that if the electron is a strain center or singular point in the æther, then corresponding to every negative electron there must be a positive one. In other words electrons must exist in pairs of such kind that their simultaneous presence at one point would result in the annihilation of both of them.

On the view that material atoms are built up of electrons we have to seek for a structural form of atom which shall be stable and equal to the production of effects we find to exist.

The first idea which occurs is that an atom may be a collection of electrons in static equilibrium. But it can be shown that if the electrons simply attract and repel each other at all distances according to the law of the inverse square no such structure can exist. The next idea is that the equilibrium may be dynamic rather than static. That an atom may consist of electrons, as suggested by Larmor, in orbital motion round each other, in fact that each atom is a miniature solar system.

Against this view, however, Mr. T. H. Jeans ('Mechanism of Radiation,' *Proc. Phys. Soc. Lond.*, Vol. 17, p. 760) has pointed out that an infinite number of vibrations of the electrons would be possible about each state of steady motion and hence the spectrum of a gas would be a continuous one and not a bright-line spectrum.

If we are to assume an atom to consist wholly of positive and negative electrons or point charges of electricity, Mr. Jeans has indicated that we may obtain a stable structure by postulating that the electrons, no matter whether similar or dissimilar, all repel each other at very small distances.

We might then imagine an atom to be built up of concentric shells of electrons like the coats of an onion alternately positive and negative, the outermost layer being in all cases negative. The difference between the total number of positive and negative electrons is the valency of the atom.

On this view an atom of hydrogen would consist of from 700 to 1,000 positive and negative electrons arranged in concentric layers in a spherical form. The vibrations which emit light are not those of the atom as a whole but of the individual electrons which compose it.

The reason for assuming that in all cases the outermost layer of electrons is negative is that if it were not so, if some atoms had their outer layers of negative and some of positive electrons, two atoms when they collided would become entangled and totally lose their individuality. There would be no permanence. Hence our present atoms may be, so to speak, the survivors in a struggle for existence which has resulted in the survival only of all atoms which are of like sign in the outer layer of electrons. We see an instance of a similar action in the case of the like directed rotation of all the planets round the sun which is due to the operation of the law of conservation of angular momentum. As a consequence of the equality of sign of the outer layer of electrons two atoms cannot approach infinitely near to each other. They mutually repel at very small distances. This suggestion makes it clear why we only know at present free negative electrons; it is because we can only detach a corpuscle or electron from the outer layer of an atom. It is clear, however, that the complete law of mutual action of electrons has yet to be determined. We have also to account for gravitation and this involves the postulate that all atomic groups of electrons without regard to sign must attract each other. Hence we need some second Newton who shall formulate for us the true law of action of these electrons which form the 'foundation stones of the material universe.' Facts seem to suggest that the complete mathematical expression for the law of mutual action of two electrons must show:

1. That at exceedingly small distances they all repel each other without regard to sign.

2. That at greater distances positive electrons repel positive and negative repel negative, but unlike electrons attract, with a force which varies inversely as the square of the distance.

3. Superimposed on the above there must be a resultant effect such that all atoms attract each other at distances great compared with their size without regard to the relative number of positive and negative electrons which compose them, inversely as the square of the distance.

In this last condition we have the necessary postulate to account for universal gravitation in accordance with Newton's law.

It is conceivable, however, that this differential or resultant uni-

versal attraction to which gravitation is due is only true of electrons when gathered together so as to form atoms. In other words, every atom attracts every other atom; but every electron does not attract every other electron. Universal gravitation may be an effect due to the collocation of electrons to form atoms and molecules, but not an attribute of electrons in themselves, though, if the gravitative effect is proportional to the product of the total number of electrons in each mass, the Newtonian law will be fulfilled. It has been also suggested that a sufficient source for the necessary resultant mass attraction may be found in a slight superiority of the attractive force between two opposite electrons over the repulsion between two similar electrons.

Conclusion.

In the above sketch of the electronic theory we have made no attempt to present a detailed account of discoveries in their historical order or connect them especially with their authors. The only object has been to show the evolution of the idea that electricity is atomic in structure, and thus these atoms of electricity called electrons attach themselves to material atoms and are separable from them. These detachable particles constitute as far as we yet know negative electricity. The regular free movements of electrons create what we call an electric current in a conductor, whilst their vibrations when attached to atoms are the cause of æther waves or radiation, whether actinic, luminous, or thermal. The æther can only move and be moved by electrons. Hence it is the electron which has a grip of the æther and which, by its rapid motions, creates radiation, and in turn is affected by it. We have therefore to think of an atom as a sort of planet accompanied by smaller satellites which are the electrons. Moreover the electrons are capable of an independent existence, in which case they are particles of so-called negative electricity. The atom having its proper quota of electrons is electrically neutral, but with electrons subtracted it is a positive atomic ion, and with electrons added to it it is a negative atomic ion. It has been shown from a quantitative study of such diverse phenomena as the Zeeman effect, the conductibility produced in gases by Röntgen rays or by ultra violet light and from the magnetic deflection of kathode rays, that in all cases where we have to deal with free moving, or vibrating electrons, the electric charge they carry is the same as that conveyed by a hydrogen atom in electrolysis.

There is good ground for the view that when a gas is made incandescent, either by an electric discharge or in any other way, the vibrating bodies which give rise to the light waves are these electrons in association with the atom. The energy of mass movement of the atom determines temperature, but the fact that we may have light given out without heat, in short, *cold light,* becomes at once possible if it is the

vibrating electric particle attached to the atom which is the cause of eye-affecting radiation or light.

Lorentz, Helmholtz, Thomson and others have shown that such a conception of atomic structure enables us to explain many electro-optic phenomena which are inexplicable on any other theory. Maxwell's theory that electric and magnetic effects are due to strains and stresses in the æther, rendered an intelligible account of electric phenomena, so to say, in empty space, and its verification by Hertz placed on a firm basis the theory that the agencies we call electric and magnetic force are affections of the æther. But the complications introduced by the presence of matter in the electric and magnetic fields presented immense difficulties which Maxwell's theory was not able to overcome.

The electronic theory of electricity, which is an expansion of an idea originally due to Weber, does not invalidate the ideas which lie at the base of Maxwell's theory, but it supplements them by a new conception, viz., that of the electron or electric particle as the thing which is moved by electric force and which in turn gives rise to magnetic force as it moves. The conception of the electron as a point or small region towards which lines of strain in the æther converge, necessitates the correlative motion of positive and negative electrons. We are then led to ask whether the atom is not merely a collocation of electrons. If so, all mechanical and material effects must be translated into the language of electricity. We ought not to seek to create mechanical explanations of electrical phenomena, but rather electrical ones of mechanical effects. The inertia of matter is simply due to the inductance of the electron, and ultimately to the time element which is involved in the creation of æther strain in a new place. All the facts of electricity and magnetism are capable of being restated in terms of the electron idea. All chemical changes are due to the electric forces brought into existence between atoms which have gained or lost electrons. If moving electrons constitute an electric current, then electrons in rotation are the cause of magnetic effects. In optics it is capable of giving a consistent explanation of dispersion, absorption and anomalous dispersion and the relation of the index of refraction to the dielectric constant. A scientific hypothesis, with this wide embrace, which opens many closed doors and enables us to trace out the hidden connection between such various departments of physical phenomena, is one which must continue to attract investigators. Physical enquirers are at present, however, groping for guiding facts in this difficult field of investigation, but we have confidence that mathematical and experimental research will in due time bring the reward of greater light.

SULFURIC ACID AND ITS MANUFACTURE BY THE CONTACT-PROCESS.*

By Dr. R. KNEITSCH.

THAT the subject on which you ask me to speak is of the greatest interest from an industrial standpoint needs no argument. The sulfuric acid industry is rightly looked upon as the foundation of inorganic technology, but it has also in the last few years, aside from its importance in so many departments of the various textile branches, become of equal necessity in the manufacture of the organic dye-stuffs. This is especially the case in the field of the alizarin dyes, and more recently, as was shown just a year ago from this platform by Heinrich Brunck, in the manufacture of synthetic indigo. If then in industries of such importance a complete revolution is taking place, a description of the discoveries and experiments which have made such a revolution possible can not fail to be of interest. In the limited time at my disposal it would be of course impossible to treat exhaustively the great mass of material bearing on the subject, and hence I must confine myself chiefly to the results of the work which has been carried on at the *Badische Anilin und Soda-Fabrik*.

The chemistry of the sulfuric acid manufacture is exceedingly simple, indeed chemistry seems at first sight to play but a subordinate rôle. Nevertheless this simple process presents an exceedingly interesting and important example of a gas reaction which occurs only at high temperatures. The reaction between sulfur dioxid and oxygen, although it is exothermic, takes place, as is well known, with extraordinary slowness, and therefore every effort has been made from an industrial standpoint to discover methods of hastening it by the use of catalytic substances. Indeed the lead chamber process itself depends upon the use of nitric acid and the lower oxides of nitrogen as such catalytic agents.

There are, however, many solid substances which have this same catalytic action, though only at high temperatures, and which in virtue of their state of aggregation suffer no loss in the process. These also possess a further great advantage over their gaseous rivals, in that their action goes on in the absence of water, thus rendering possible the

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production, not of dilute acid only, as in the chamber-process, but of the strongest acids and of sulfur trioxid itself.

Historical.

In the historical development of the contact-process we recognize four periods, the first of which was ushered in by the discovery in 1831 by Phillips of the catalytic action of platinum in the manufacture of sulfuric acid. The second period dates from the discovery by Woehler and Mahla, in 1852, of a similar catalytic action on the part of a number of other substances, and the explanation of the mechanism of the reaction in some of these cases. The third period, which begins with Winckler, is characterized by the use of certain gaseous mixtures which, according to the conception of that time, were especially favorable for the reaction from a quantitative standpoint. In the fourth period there is a return to the use of the gases from the pyrites-burners. As their ultimate goal, the early efforts, like those of the present period, seek by the aid of the catalytic process, entirely to replace the lead chambers in the manufacture of ordinary sulfuric acid, while the workers of the third period, profiting by the large number of earlier failures, confined themselves to the attempt to make the expensive fuming acid.

The discoverer of the catalytic action of platinum in general was Sir Humphry Davy, who found that when a heated platinum wire was brought into a mixture of oxygen or air with hydrogen, carbon monoxid, ethylene or cyanogen, it became red hot, and the gas mixture was burned, generally slowly, but sometimes with great rapidity. Three years later Edmund Davy discovered that finely divided platinum, prepared by evaporating the nitrate and treating the residue with alcohol, was brought to a glow by moistening with alcohol, the alcohol itself being ignited. Doebereiner found in 1822 that the residue left on heating ammonium platinum chlorid, acted in the same manner, and in 1823 he discovered that when a stream of hydrogen impinged on finely divided platinum, it took fire. The next year he brought out the celebrated Doebereiner lamp, which depended on this phenomenon.

The honor of having applied this catalytic action of platinum to the manufacture of sulfur trioxid belongs, as has already been said, to Peregrine Phillips, Jr., a vinegar-maker of Bristol. In 1831 he received an English patent for his discovery. This discovery of Phillips' was confirmed in 1832 by two distinguished German scientists, Doebereiner and Magnus. Seventeen years passed with no further developments, and then the Belgian chemist, Schneider, announced that he had solved the problem of manufacturing sulfuric acid without the aid of lead chambers. He believed that he had found in a specially prepared pumice-stone a catalytic substance of extraordinary activity,

but although great claims were made, no practical results followed.

The hopes of this period are well characterized in a letter which was written by Clement-Desormes to Schneider in 1835, only four years after Phillips' discovery. A portion reads as follows:

> I am convinced that within at the most a decade sulfuric acid will be made upon a large scale without the use of lead chambers, nitric acid, or nitrates; do not let your courage fail, but press forward to this important goal.

Thus early was the goal definitely pointed out. . . . In the year 1852 came the discovery of Woehler and Mahla, that the oxids of copper, iron and chromium exert a similar catalytic action upon a mixture of sulfur dioxid and oxygen, to that of platinum sponge and platinum foil. The mixture of copper and chromium oxids was found to be particularly active in this respect. This was followed by the discovery of many other catalytic substances, such as 'spent' pyrites, highly heated quartz, platinized pumice, platinized asbestos and platinized clay.

This second period in historical development is, like the first, characterized by the attempt to solve the problem of the manufacture of ordinary sulfuric acid without recourse to the chamber process. These efforts, however, were crowned by no practical success, indeed it was not found possible even to make fuming sulfuric acid cheaply enough to compete with that obtained by the distillation of the iron vitriol shales.

We now come to the turning point of our subject, the work of Clemens Winckler. By his experimental investigations he reached the conclusion that for complete conversion into sulfuric acid, it was necessary that the mixture of sulfur dioxid and oxygen should be in stoichiometric proportions, that is, two volumes of the oxid to one of oxygen and that all other gases, even oxygen in excess, exercised an injurious effect upon the reaction. This mixture Winckler prepared very simply by the decomposition of ordinary aqueous sulfuric acid with heat, subsequently removing the water. In this manner, by combining the gases, he obtained sulfur trioxid or fuming sulfuric acid at will.

This conception of the suitable conditions for the success of the contact process seemed at that time exceedingly obvious, and well calculated to explain all the failures which had attended every attempt to utilize the gases of the pyrites-burners by Phillips' process. Winckler's work attracted great attention and for a long time dominated all further experimentation in connection with the contact process. At about this time a similar process for the manufacture of fuming acid was discovered in Messel's works and was protected by patents. Winckler also brought out a more advantageous method of preparing

the contact substance, that of reducing the platinum by the use of formic acid salts. This keen discovery of Winckler's brought at once into existence a new industry, that of the synthetic manufacture of fuming sulfuric acid. A number of works immediately adopted Winckler's process, among them first the *Badische Anilin- und Soda-Fabrik,* while the monopoly of Stark in Bohemia was broken. The whole industry therefore owes Winckler a debt of gratitude for this advance in technology.

Further work in this field was wholly under Winckler's influence. This is true of the patent secured ten years later by Haenisch and Schroeder, who replaced pure oxygen by atmospheric air, retaining, however, the use of pure sulfur dioxid, and compensating for the diluting influence of the nitrogen by carrying on the reaction under pressure, in order, as the patent reads, that the molecules of the gases may be brought closer together. This process also was put into practical application in the *Badische Anilin- und Soda-Fabrik.*

Messel and Lunge proposed a method of obtaining a stoichiometric mixture and at the same time excluding the atmospheric nitrogen by burning the pyrites with pure oxygen. All these processes were unsuited by their very nature to compete with the lead chamber process and were necessarily confined to the manufacture of the fuming acid. Nevertheless attempts at the solution of the larger problem were by no means wanting; little, however, regarding them made its way to the notice of the public. Winckler especially published nothing regarding his new work along this line, so that it only became known last year, through the striking lecture of Lunge and Winckler in Hannover on the development of sulfuric acid manufacture, that at his instance it had been found possible at the Mulden works to convert from two thirds to three fourths of the sulfur dioxid in the pyrites-burner-gases into sulfuric acid.

Purification of the Gases.

The solution of the problem of the complete conversion of the burner-gases into sulfuric acid remained unsolved, and indeed at that time, as far as was known, theoretically or practically, was unsolvable. Nevertheless, as I attacked the problem at the Badische works, it was chiefly theoretical considerations which made the possibility of attaining this great goal seem not absolutely out of the question.

It is well known that in the lead chamber process there is always an excess of six volumes per cent. of oxygen in the gases as they leave the chambers. In working with pyrites-burner gases under similar conditions, there would naturally always be this excess of oxygen, whatever contact-method was employed for making the acid, and it could not be understood why in spite of such an excess of oxygen the reaction should not proceed quantitatively. The question was tested

experimentally with gases which were intentionally much diluted, pure sulfur dioxid with a large excess of air being used, and it could be demonstrated that the reaction did not fully cease, under certain circumstances, until the sulfur dioxid was almost completely converted into sulfuric acid. Strangely enough, even when double the theoretical amount of air was present, it seemed to have no untoward influence upon the reaction, indeed it rather appeared as if the large excess of oxygen exercised a favorable effect upon the quantity of sulfur trioxid obtained from a given quantity of the dioxid. From this it followed that the earlier conceptions, according to which the dilution of the sulfur gas was unfavorable for the contact-process, must be submitted to a critical examination.

From now on the experiments were carried out upon the gases which came directly from the pyrites-burners. For this purpose the gases were brought directly from the pyrites-burners to the laboratory through a long lead pipe. This pipe acted as a long dust catcher, and the gases in their passage through it were thoroughly freed from every mechanical impurity, such as ashes, burner-dust, etc. The gases were further passed through several bottles filled with sulfuric acid, before they reached the contact mass. The experiments were very satisfactory, for quite as favorable results were attained as had been the case with the mixture of pure gases. No diminution in the activity of the contact mass could be observed, although the experiments extended over several days, and the hope seemed well justified that in this simple manner it would be possible to manufacture sulfuric acid directly from the burner-gases without loss of sulfur.

The experiments were now carried out on a larger scale. Here, however, it soon appeared that the activity of the contact-mass rapidly diminished in strength and finally ceased. The results were the same, even after the gases had been not only purified as in the laboratory experiments, by cooling in long tubes and washing repeatedly with sulfuric acid, but in addition had been passed through a dry coke and asbestos filter; they were then as pure as was technically possible. We were, therefore, obliged to consider the experiments on a large scale as a failure.

Although by these unlooked-for results a hard blow was given to the hope of success, nevertheless further experiments were undertaken in the laboratory for the purpose of investigating the cause of the apparently inevitable deterioration of the contact-mass.

The surprising observation was soon made that there are substances which, when present in exceedingly small quantities, are capable of inhibiting the catalytic action of platinum to an extraordinarily great degree. Among these substances are first of all arsenic, mercury and phosphorus, while antimony, bismuth, lead, iron, zinc and the other sub-

stances, which are liable to be present in the burner-gases, are only injurious to the extent to which, when present in large quantities, they cover up and choke the contact mass. The injurious action of arsenic, for example, is so great that when present to the amount of only one or two per cent. of the platinum in the contact-mass, the latter becomes completely inert. Hence by these investigations, it was incontrovertibly proved that there are substances which are capable of exerting a specific action, 'poisonous,' one might almost call it, upon the contact-mass. The question now was as to whether there was present in the burner-gases, in spite of the efforts at purification, such a substance.

There was, in fact, in these gases a trace of white fume of sulfuric acid which could not be removed, and this was found still to contain arsenic derived from the pyrites. But even if the failure of the process on a large scale was owing to a now known cause, the remedy was not apparent. At that time the complete precipitation of this white fume, the so-called 'huttenrauch,' was considered by the most distinguished experts as technically impossible.

Although after such long and careful work, the prospects of future success had become very slight, nevertheless, since the cause of the previous failures was known, fresh energy was applied to the solution of the new problem. This was nothing less than the attempt to free the burner-gases completely from *all* impurities, so that finally there should remain absolutely nothing but the pure gases, that is, sulfur dioxid, oxygen and nitrogen.

With an enormous expenditure of time, care, money and patience, experiment after experiment was undertaken in the effort to reach this goal, and it may well be said without exaggeration that it has been one of the most difficult problems of modern industry which has had to be solved, in order to render possible the present revolution in the manufacture of sulfuric acid. It would carry us too far to go into the particulars of the various experiments. Even since the process has been put into operation on a large scale; it has demanded several years of the most assiduous work, before it has become possible to look upon the purification of the burner-gases as absolutely assured. The great difficulty of the task lay in the fact that it was a continual struggle with an invisible enemy, as one might say, and that every mistake paid the penalty of permanent damage to the plant as regards the amount of production. The final result of these labors was that it was in fact found possible to free the burner-gases from every trace of every impurity, if after appropriate treatment and cooling, they are made to undergo a thorough, systematically continued scrubbing with water or sulfuric acid. This must be continued until both optical and chemical examination of the gas assures us of complete purification from every injurious substance. How this thorough scrubbing is carried out with

the purifying fluids is a matter of indifference in the final result. Thorough scrubbing and wet filtration, each by itself, or both together, bring us at last to the same point. Only a few of the difficulties which appeared in the application of gas purification on a large scale may be mentioned here.

For the success of the process it had proved necessary that the gases should be cooled slowly. It is a curious fact, and one as yet without due explanation, that the sulfuric acid fume from the pyrites-burners is far more difficult to remove when the gases are cooled rapidly than when they are cooled slowly.

For this purpose long iron conductors were used, which were kept cool by the circulation of the air. As far as our knowledge went at that time, these iron conductors could occasion no untoward influence upon the contact-process; for when dry pyrites are used in the burners, the sulfuric acid in the gases has a concentration of at least ninety per cent. Should this act on the iron at all, it would result in the formation of sulfur dioxid, and this could of course do no damage in the process.

But now in spite of the fact that the gases were freed from every mechanical impurity, so that the optical test, which was at that time considered sufficient, betrayed not the slightest sign of any solid or liquid particles (for the sake of absolute certainty the gases were finally passed through a kind of wet cloth filter, somewhat like a filter press), still the contact-mass gradually diminished in activity. This diminution was very slow it is true, being apparent only after weeks or perhaps months, but it was nevertheless certain to occur. It was only after long and difficult labor that the presence of arsenic was again proved to be present in the contact mass, and this, after it was supposed that every trace of the element had been eliminated in the process of purification. The contact-mass, however, showed unmistakably that arsenic was in evidence, and the suspicion arose that the cause of all the trouble might be due to the action of the condensed sulfuric acid upon the iron cooling-conductors. Further investigation showed that this was probably the case, and that by this action some gas which contained arsenic must have been formed. This gas was probably arsin, the hydrid of arsenic.

A change in the arrangements was now made so that the condensed sulfuric acid could no longer come into contact with the iron conductors, and from this time on the contact-mass remained undiminished in its activity. It appears from this that, contrary to the generally received ideas, hydrogen can be evolved by the action of concentrated sulfuric acid upon iron, and that when arsenic is present, arsin may be also formed.

With this indeed ended the hardest struggle which met us in the attempt to introduce the new sulfuric acid process into technical industry. It was, however, by no means the last contest. When the process came to be put in operation on a larger scale, new difficulties in purifying the gases appeared, whose cause was almost as problematical and unforeseen as those which have been already described.

When the pyrites-burners were used to their full capacity, fumes were formed which seemed to mock every effort at absorption. Their cause was finally found to be the presence of unconsumed sulfur in small quantities. Like the quickly cooled sulfuric acid fume, this sulfur proved exceedingly difficult to remove. But how could this unburned sulfur be detrimental, when in the contact-apparatus it would burn to sulfur dioxid and sulfur trioxid? The explanation rests in the fact that this sulfur fume again contains traces of arsenic. This also it was unconditionally necessary to remove.

A radical means for this was finally found in thoroughly mixing the gases while still hot, so that the combustion of the last trace of sulfur was ensured. This mixing was accomplished by the injection of steam, which was found to have other and not less important advantages. It especially served to dilute the concentrated sulfuric acid in the gases, so that they were no longer condensed in the preliminary cooling conductors, and hence the evolution of arsin was avoided; when finally condensed in the chief cooling apparatus which was made of lead, they were so much diluted that they ceased to corrode the metal. Furthermore the formation of hard dust-scale in the various conductors was prevented, and danger of these becoming stopped up was avoided.

* * * *

In closing this lecture I may be permitted to place before you what a development the sulfuric acid manufacture has enjoyed in our works alone, since the introduction of this contact-process. The annual production of sulfuric acid anhydrid has been:

In 1888	18,500 tons.
In 1894	39,000 tons.
In 1899	89,600 tons.
In 1900	116,000 tons.

For the accomplishment of such a work the powers of a single individual were naturally far too limited. It required the powerful assistance of an establishment like the Badische Anilin- und Soda-Fabrik, the keen and far-seeing direction of a Heinrich Brunck, the experience of a Gustav Jacobsen, and the intelligent help of distinguished engineers, to bring to a successful completion such results as those I have endeavored to describe in this lecture, and which stand as an honor to the industrial progress of our fatherland.

THE PHYSICAL BASIS OF HEREDITY.*

By Professor CARL H. EIGENMANN,
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'HE is a chip of the old block' is the popular expression used in applying the best known general law of heredity that 'like begets like' to a particular case. But in saying so we state but half the truth. The chip is like the block and not like the block. Each individual is unique; no two were ever cast in the same mold.

There are always two phenomena associated in the development of a new individual. One is the repetition in the offspring of characters possessed by his ancestors, either near or remote. The second is the formation of new characters which have never appeared before in any individual. I shall confine myself to the first of these phenomena.

What characters has any individual inherited from his ancestors and what ones are new to him is always a question of the first consideration in a study of heredity. The consideration of which of these he may transmit to his offspring naturally follows.

He has always inherited and always transmits those characters that distinguish his species, race or family from other species, races or families. A backbone, four limbs and hairiness are always inherited and transmitted by a mammal, as backbone, four limbs and feathers are always transmitted by a bird. The erect position, peculiarities of hand and foot and those other features which together make a man are always inherited and always transmitted. The inheritance and transmission of the racial characters of the Jews distinguish them from all the various peoples with which they are found. The same is true of the Chinese, Indians, Negroes and, to a less degree, of the less pure races of Teutons and Anglo-Saxons.

Aside from characters that are *always* inherited and transmitted, there are groups of characters that may have been inherited and that are transmissible, but that are not necessarily *transmitted*. It is the peculiar combination of some of these characters that constitutes family traits. These transmissible, but not necessarily transmitted, characters may be anatomical and range from the height of the individual to such minute details as moles, a few long hairs in the eyebrows or even smaller details.

They may be physiological. Longevity is transmissible; so are a

* Photographic illustrations by D. W. Dennis.

tendency to fatness and leanness and, in the males of certain families, a tendency to baldness. The members of some families have a tendency to become corpulent at a certain period, and no reasonable amount of starving seems to affect this tendency. After half the inmates of Andersonville prison had made their escape, one of these hereditarily stout individuals even after weeks of starving became fastened in the tunnel, preventing the escape of the rest of the prisoners. The members of other families remain 'hungry Cassiuses' however well they may be fed.

Mental peculiarities are transmissible. Sometimes one mental trait of the parents is transmitted to one child while others are transmitted to another. Weit Bach, a baker who lived in the middle of the sixteenth century, was a mild form of a musical prodigy. He transmitted his musical talent through at least eight generations, and hundreds of descendants, twenty-nine of whom became famous musicians. The case of the Jukes family is well known. In the course of six generations of descendants from one woman 52% of the female descendants became public women, 23% of the children were illegitimate. There were seven times more paupers among the women than among all women, and nine times as many among the men.

We have, then, characters that are always transmitted and characters that may be transmitted. As a third group we have characters concerning which we have doubt, and, at present, much discussion. This third group of characters includes individual peculiarities which have not been inherited, but are acquired during the lifetime of the individual as the result of his education, his activities and the effect of the climate and other elements of his environment. Whether or not these are transmissible has been the question of the past ten years. The discussion was started by Weismann, who denied, for theoretic reasons, that any of the characters so produced are transmissible. It is agreed that the individual characters that result from accidental or voluntary mutilations are not transmitted. Wooden legs are never transmitted. Wooden heads sometimes are!* Many instances have been brought forward to prove the transmissibility of acquired characters, but none of these cases has been accepted as conclusive. From my own studies of the effect of disuse on eyes and the absence of light on color, I am convinced that the results of the activities and the characters due to the environment are transmissible. Mehnert goes so far as to maintain that races are progressing in so far as marriage does not take place until comparatively late in life, and children are not born till the molding effects of activities and environment have individualized the parents. Sargent, of the Harvard gymnasium, evidently convinced of the transmissibility of acquired characters, advises the delay of marriage

* With apologies to Dr. E. G. Conklin.

among Cubans until full maturity, as a means of raising their physical standard. He found that at present the average Cuban man is, in size and weight, the equal of the American female student.

An illustration of environment, including education, overcoming hereditary tendencies has recently been brought to my notice by Mr. A. J. Redmon. Mr. Redmon reared two murderous sparrow-hawks in a cage with young larks and wrens. "They all grew up together; the little wrens would creep under the sparrow-hawks for protection at night. The two hawks never attempted to hurt the larks or wrens." Mr. Redmon tried to starve the hawks into killing birds, but they utterly refused to disgrace their education.

Galton has determined just how much, on an average, each ancestor contributes to the peculiarities of an individual. The parents together contribute one half of the total heritage, the four grandparents together one fourth, the eight great-grandparents one eighth, the sixteen great-great-grandparents one sixteenth and all the remainder of the ancestry one sixteenth.

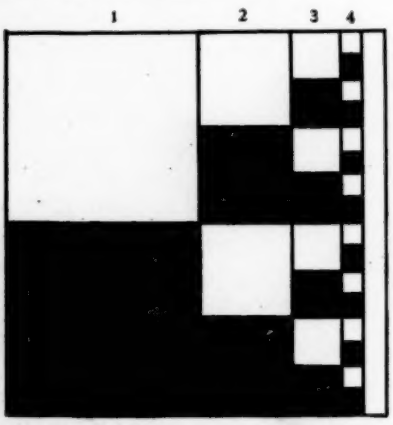


FIG. 1. AVERAGE CONTRIBUTION TO THE PECULIARITIES, OR DEVIATION FROM THE AVERAGE, OF THE INDIVIDUAL, by the first, second, third, fourth and remaining generations; father and mother each contribute one fourth together one half of the total heritage. Each one of the grandparents contributes one sixteenth or together one fourth. The great-grandparents together one eighth, the great-great grandparents together one sixteenth, and all the remoter ancestry together one sixteenth. *After Meston.*

This law explains another—that the offspring of exceptional parents are, on an average, less exceptional than their parents. Supposing that the average height of two parents exceeds the average height of the race by three inches. The average of the grandparents and remoter ancestors will differ from the average height of the race by much less than this. Since the ancestors beyond the parents contribute one half the entire heritage of the individual, they will act as a drag to pull the individual toward mediocrity, in the present case by one inch. This law acts impartially, so that the offspring of the extremely good and the extremely bad are both saved from the fate of their parents.

This regression toward mediocrity may readily be overcome by selective breeding. In race-horse breeding if the ancestry has been good for three or four generations the rest are not considered.

Galton has devised a forecast machine by which, if the height of the parents is known, the average height to which the offspring will grow

may be determined. "Of the individual we can assert nothing as certain, only state the probable."

It is evident from these laws that, if any fond parents feel that they are in any way remarkable, their apparently remarkable offspring are on an average only two thirds as remarkable as they themselves. Also if there are any fond sons or daughters who rely on really gifted parents for their standing among their fellows, the sooner they begin to look to themselves to make up by individual effort their probable loss by the law of regression the better, for, on an average they are but two thirds as gifted as their parents. I should not mention this fool-killing law if it did not have its bright side. If any individual feels it in him to do and be something, a mediocre parentage need not discourage him, for, on the average, exceptional individuals, as we all think ourselves to be, exceed the average of humanity by one half as much again as their parents exceeded this average. (Fig. 3.)

It is a reassuring fact that, starting from any standpoint above the average, our relatives are on the average not quite equal to us. Moreover, a gifted individual is more likely to be the exceptional offspring of mediocre parents than the average offspring of gifted parents. "Among mankind we trust largely for our exceptional men to extreme variations occurring among the commonplace."*

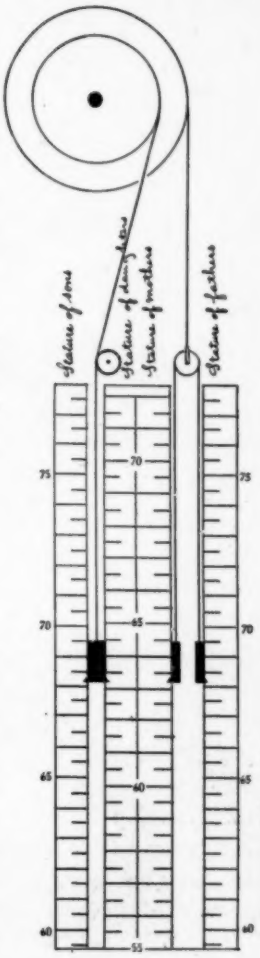


FIG. 2. GALTON'S FORECAST MACHINE FOR STATURE, SET AT MEDIOCRITY OF THE RACE; The average height of men being about 68.25, that of women 63 25. The circumference of the wheels at the top are to each other as two to three. If the average height of the parents is increased or decreased above or below mediocrity by a given quantity the average height of the offspring is increased or decreased by two thirds such amount. To convert the female statures into the corresponding male stature, multiply the female stature by 1.08.

* Galton in his 'Hereditary Genius' found one hundred gifted men to possess on an average the following number of relatives equally gifted:

	Gr.-grandfathers 3	
	Grandfathers.....17	
Brothers 41	Fathers 31	Granduncles..... 5
Nephews.....22	Gifted Men.....100	Uncles..... ..18
Grandnephews.. 10	Sons 48	Cousins.....13
	Grandsons.....14	
	Great-grandsons.. 3	

The isolation of gifted men is graphically illustrated by arranging the facts given in the middle line in a frequency polygon. (Fig. 4.)

What is the physical basis—the vehicle for the transmission of all the characters large and small, from one generation to the next?

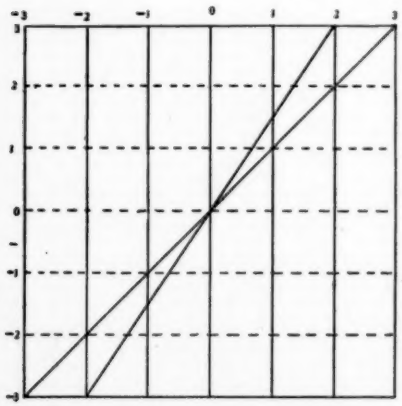


FIG. 3. GALTON'S REGRESSION DIAGRAM. Horizontal lines indicate the deviation of the average of the height of the father and mother above or below the race, O; the vertical lines indicate the average filial deviation from the average of the race.

If the deviation of the sons from the average of the race equaled the deviation of the parents a line joining the various filial heights would give us the diagonal from 3 to 3. Actually the line joining filial heights is the one from 2 to 2, which is only two thirds as far from 00 as the line 3, 3.

buds develop at certain regions and grow into a new individual. Here any one group out of a large number of groups of cells may build up a new individual. If a hydra be cut in any one of hundreds of possible ways each part will regenerate the portion lost, and so form a new individual. Every group of cells is here adjusted to reproduce the entire individual if the inhibition exercised by the presence of other cells is removed. The method of budding is the commonest means of transmitting the characters in plants. Those individuals produced by buds are usually exactly, or very nearly, like

In many minute animals and plants where the individual consists of a single cell it simply divides into two, so that it is impossible to say which of the two is the parent, which the offspring. Heredity is here simply a process of growth and division. If one of these individuals is cut into halves each half will regenerate the part lost. Normally the whole animal or plant is concerned in heredity. In fact, an individual may be divided in any way and each fragment will regenerate the lost part so long as the fragment contains part of the nucleus.

In many other animals, of which we have a representative in our ponds and streams in *Hydra*,

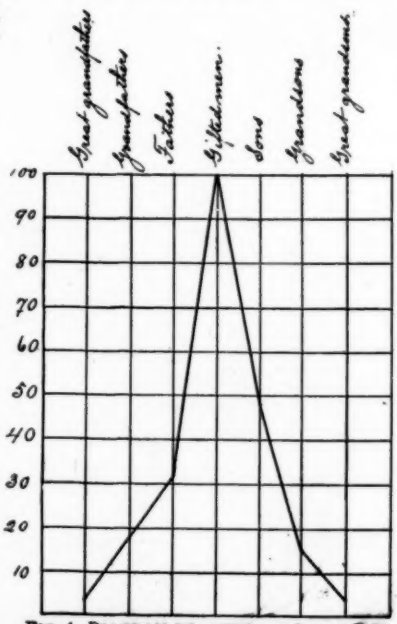


FIG. 4. DIAGRAM SHOWING THE SMALL PERCENT. OF RELATIVES OF GIFTED MEN WHO ARE GIFTED.

the parents, a fact of which advantage is taken to preserve the peculiar characters of our varieties of fruit, all of which are perpetuated by grafting, or by means of runners.

In some worms the power of developing a new individual if part of the old one has been lost has been modified so that the lost parts are reformed before they are really lost. A given limited part of the middle of the body has the habit of forming a new head for the part behind, and a new tail for the part in front. A string of individuals is formed in this way joined tandem. These separate after some time and each new individual repeats the process.

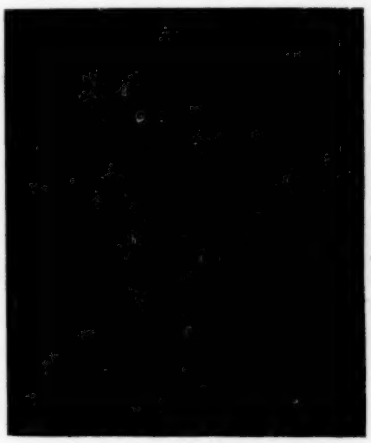


FIG. 5.

FIG 6

FIG. 5. HYDRAS: THE ONE AT *c* WITH BUDS; THE ONE AT *d* WITH SEX-ORGANS. FROM LEUCKART.

FIG. 6. AN ARM OF A STARFISH REPRODUCING FOUR LOST ARMS.

These methods of forming new individuals are occasional. Each method is restricted to some limited group of species. In practically all animals in which these occasional methods of reproduction occur, they alternate with sexual reproduction. In the great majority of animals sexual reproduction is the only means of transmitting characters to a new generation.

By sexual reproduction we understand the development of a new individual from a single cell which is usually produced by the fusion of two cells.

Just a word as to what we mean by a cell. The word has a penitentiary flavor that may be misleading. A cell is a mass of protoplasm enclosing a differentiated portion or nucleus. The nucleus contains, among other things, during certain phases of cell life a definite number of thread-like bodies called chromosomes. The number of chromosomes differs in different animals, but is always the same in the different cells of the same animal.

In unicellular plants, and in some protozoans, two individuals physically alike, or nearly alike, and moving about in water, unite to form a single individual. In animals more complicated entire individuals no longer merge into one; but this function has become restricted to certain cells, just as the function of moving the animal from place to place has become restricted to certain cells. In the majority of animals living in water these cells are liberated in the water, and here two cells unite, as in lower forms two individuals unite.

The cells uniting are equally important in transmitting hereditary characters, and in their essential structure. As an adaptation to the necessity of the union of two cells and to the necessity that the combined volume of the two cells be sufficient to give the new individual a fair start, the cells, as the result of a division of labor, have become very different in shape and action. One has taken upon itself the function of providing the nutriment necessary to start the new indi-

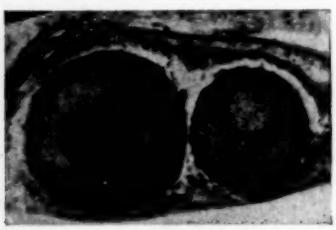


FIG. 7.

FIG. 8.

FIG. 7. TWO TYPICAL CELLS; OVARIAN EGGS OF CYMATOGASTER.
FIG. 8. PHOTOGRAPH OF THE CONJUGATION OF TWO STRINGS OF INDIVIDUALS OF SPIROGYRA; at *a* the contents of one individual are passing over into the next; at *b* the contents of two individuals are united within the wall of one; at *c* the two uniting individuals have been metamorphosed into a spore; *d*, a bachelor which missed a mate.

vidual, and has become comparatively large and inactive. The other has taken upon itself the function of providing the mobility necessary to insure the union of the two cells. It has become excessively minute, and very mobile. The differences in the cells concerned in sexual reproduction extend to the ducts through which the cells are emitted, and secondarily to the whole individual, so that in every organ, function and psychical trait male and female are different.

Into the question of the advantages of the production of a new individual by the union of two cells we can not enter in detail. Suffice it to say that on the part of some it is looked upon as the union of two hereditary tendencies, which eliminates extreme badness, or what amounts to the same thing, extreme goodness that may be inherent in one of these tendencies, and at the same time insures new combinations of characters from which nature may select the fit.* On the

* Pearson has demonstrated mathematically by comparing parents with offspring that 'whatever be the physiological function of sex in evolution, it is not the production of greater variability.'

part of others it is looked upon as a means of rejuvenescence or union of energies to insure the continuance of life for another span. Loeb has found that an egg that will under all normal conditions develop only after a male cell has entered it, may be caused to develop without the male cell by placing it for a short time in a solution of higher osmotic pressure than that in which it is normally found. It is thus seen that one function of the male cell is either to supply stimulation to the egg to cause it to develop, to regain the lost power of dividing, to rejuvenate it or to act as a catalyzer. But it has long been known that the child may inherit from the father. Indeed, Boveri has shown that the male cell can also develop alone into a new individual if it is supplied with a proper medium of sufficient size.

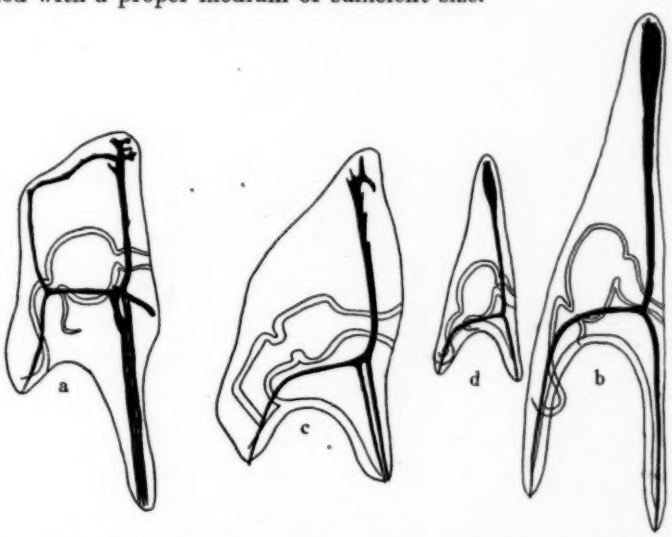


FIG. 9. *a*. LARVA OF SPHÆRECHINUS GRANULARIS. *b*. Larva of *Echinus microtuberculatus*. *c*. Hybrid of *Sphærechinus* egg and *Echinus* sperm, showing blended characters. *d*. Fragment of *Sphærechinus* egg, fertilized with an Echinus sperm, showing paternal characters only.

The egg and the sperm are thus seen to equally contain the hereditary tendencies necessary to form a new individual. Since the offspring frequently resembles both parents this result is evidently caused by the mingling of the two hereditary tendencies.

Boveri's experiment brings us naturally to the question as to where in the hereditary cells the power of reproducing all the complicated transmissible parts lies. In spite of the fact that it is inconceivable that the many hereditary qualities of, say an elephant, should be compressed into two cells, one just large enough to be seen with the unaided eye and the other far too small to be seen without the microscope, he has demonstrated that the hereditary plasma is restricted even to certain parts only of these cells.

The eggs of a sea urchin, *Sphærechinus,* which normally develop into a well-known larva, were broken by Boveri into two in such a way that the nucleus was all contained in one fragment. Male cells of another species of sea urchin, *Echinus,* having a well-known, but quite different, larva, he then caused to enter the fragment without a nucleus. A larva developed which possessed all the characters of the larva normal to the male used in the experiment. Since cell contents of both species were present and nuclear structures of only one, and the larva resembled the species represented by a nucleus, it was concluded that the hereditary substance is located in the nucleus. The nucleus, then, contains the physical basis of heredity.

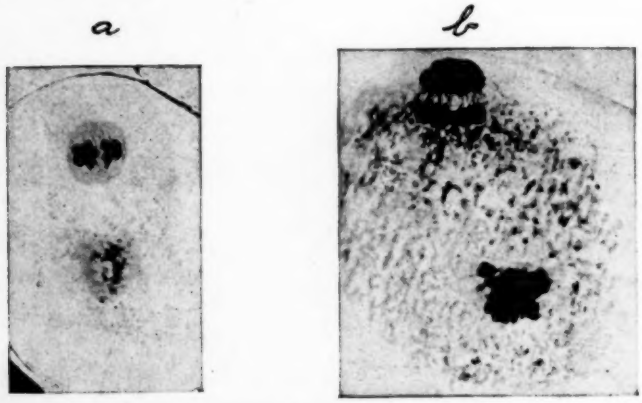


FIG. 10. *a.* THE EARLY STAGE IN THE MATURATION OF THE EGG. The four chromosomes have been reduced to two tetrads. Eventually three out of each group of four granules will be eliminated from the egg. *b.* The elimination of two of the granules of each tetrad in the formation of the first polar body.

Boveri's results were looked upon with much suspicion until they were confirmed by Delage. With a German and a Frenchman agreeing we may safely consider this point as settled.

The intimate process of the preparation of the hereditary cells for their union and the union of the cells have been the subjects of many monographs during the last twenty years.

Since each cell has a definite number of chromosomes and this number would be doubled by the union of two cells elaborate provisions are made by the cells to reduce this number to one half before the union of the two cells takes place. The study of the methods of this reduction has engaged a host of cytologists during the past ten years, and innumerable papers have resulted.

It is evident that the great difference between the two cells is simply an adaptation to insure their union, for, after uniting, their nuclei, the physical basis of heredity, become alike (*c* in figure 11).

Credit for the great activity in research along this line must be

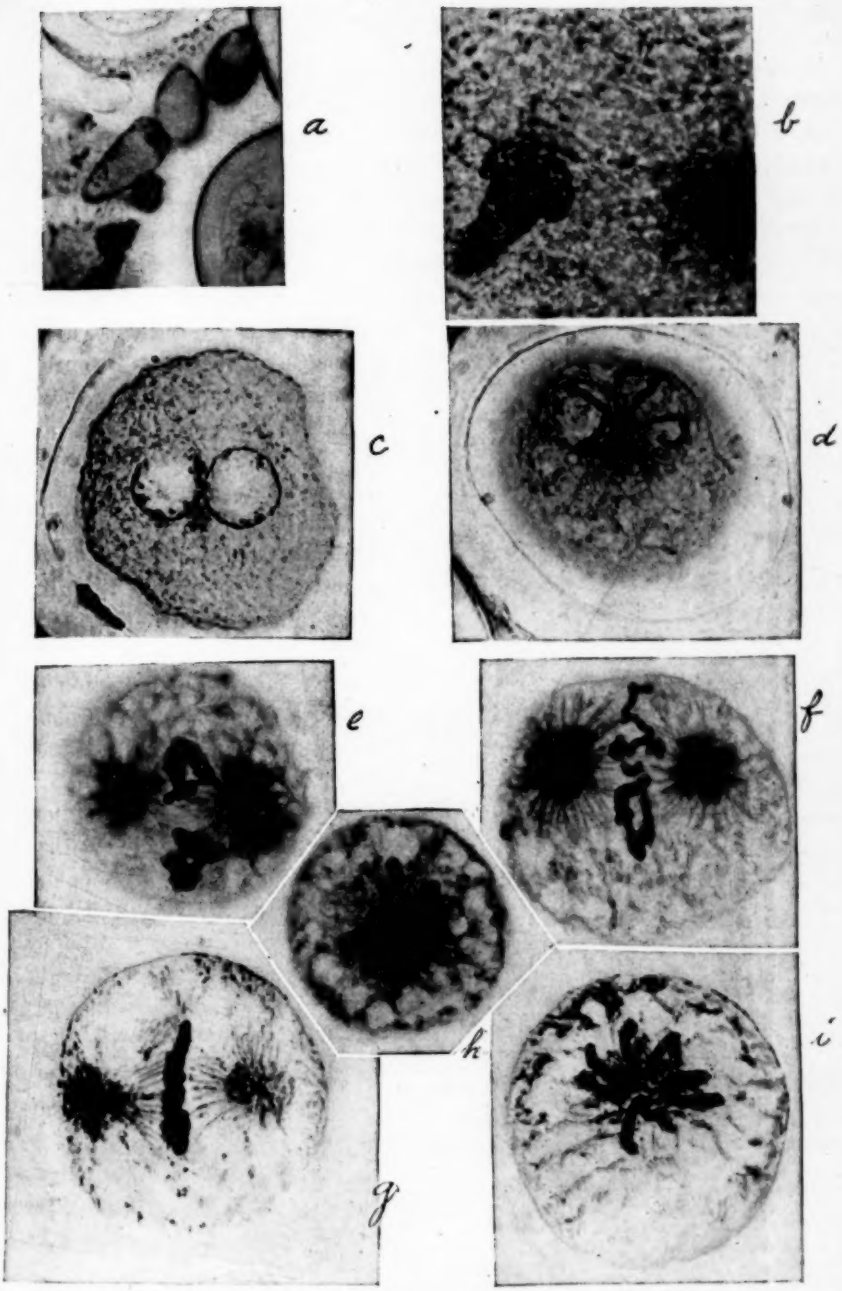


FIG. 11. INTIMATE PROCESSES IN THE UNION OF TWO REPRODUCTIVE CELLS FROM PHOTOGRAPHS OF ASCARIS, all but *b*, with an initial magnification of 1,500 diameters. *a*. A spermatozoon. *b*. A spermatozoon in the egg very highly magnified. *c*. Male and female nuclei after assuming the resting stage. *d*. Male and female nucleus coming out of the resting stage, the chromatic threads assuming definite shape. *e*. The threads from two nuclei being pulled together. *f*. A late stage of the same process. *g*. The completion of the process. *h* and *i*. Two eggs in the stage presented by *g*, but seen from one of the poles of the egg; two of the threads shown in both *h* and *i* are derived from the father and the other two from the mother.

largely given to Weismann. The method of reduction imagined by him accounted for the origin of variation in the offspring, and thus furnished him with an explanation of the advantages, and therefore the existence of sexual reproduction. It was the attempt to verify or reject his theory which called forth so many monographs on this subject.

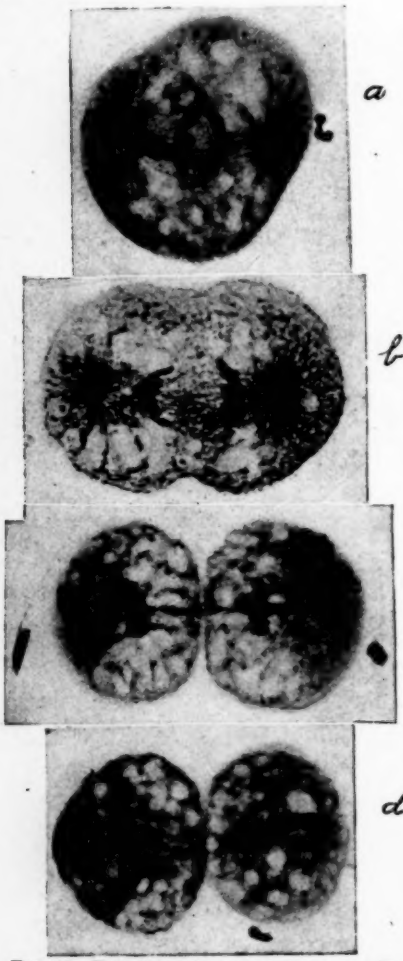


FIG. 12. THE EARLIEST STAGES IN THE DEVELOPMENT OF THE NEW INDIVIDUAL. *a*. The separation of halves of the chromatic threads. *b*. Further separation and beginning of division of the egg. *c*. Complete separation and complete division of the egg. *d*. The two cells with their chromatic threads ready to divide again.

We shall not here go into details of the process of the reduction of the number of chromosomes. The most favorable objects for demonstrating many of the processes of maturation and fertilization are the reproductive cells of *Ascaris*. In *Ascaris* each of the nuclei is finally seen to contain two chromatic threads and the ultimate and intimate process of fertilization is seen from the photographs to be the union of these two groups of two chromosomes into one group of four chromosomes ready to divide. The dynamic agents in their union are two darkly stained bodies from which rays emanate, the centrosomes. In the present case one of these enters the egg with the sperm and this is the usual method of its origin in developing eggs. At the completion of the process of fertilization we have a cell containing a nucleus with the number of chromosomes normal to the species. One half of these chromosomes came from the father, one half from the mother. When this cell divides each one of the chromosomes divides longitudinally, and one half of each chromosome goes to one of the new cells and the other half to the other cell. The observations of Rückert, Häcker and Moenkhaus

make it probable that this process is continued with every division, so that ultimately each cell of the adult contains chromosomes, one half of which are the lineal descendants of the chromosomes coming from the father, the other half lineal descendants of the chromosomes coming from the mother. Rückert has found that in a late stage of development in a crustacean the chromosomes were in two groups, presumably maternal and paternal. Moenkhaus has found that in crossing two species of fishes with structurally and physiologically different chromosomes these retained their structural and physiological differences for a number of divisions. From the elaborate provisions to insure the union of the chromatic threads it is quite certain that they, finally, are the carriers of the hereditary power.

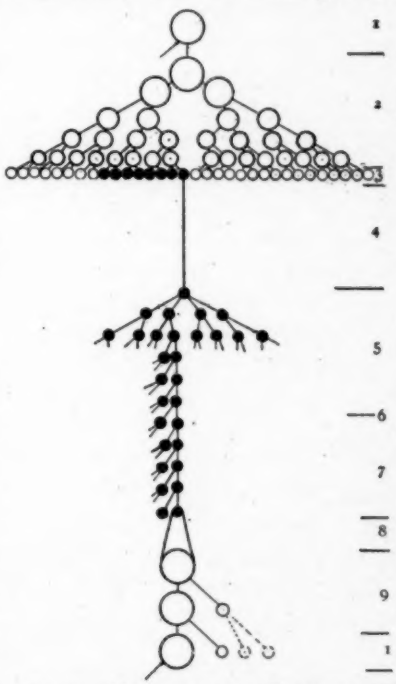


FIG. 13. HISTORY OF THE REPRODUCTIVE CELLS IN CYMATOGASTER, FROM THE BEGINNING OF ONE GENERATION TO THE BEGINNING OF THE NEXT. 1. Fertilization of the egg. 2. Segmentation of the egg. 3. Segregation of the reproductive cells. 4. Period of inactivity. 5. Multiplication of the cells originally segregated. 6. Time of the differentiation of the sexes. 7. Continued multiplication of the cells in the female. 8. Period of growth of the individual cells. 9. Period of maturation.

The character of any cell is controlled by the nucleus it contains, and, since we have seen that the nucleus contains two different groups of chromosomes, one group containing the peculiarities of the father and the other the peculiarities of the mother, the cause of the blending of the two sets of characters in the offspring becomes apparent and the greater resemblance in some characters to one parent and in other characters to the other parent may readily be inferred.

Without attempting to review the recent speculations and observations on the origin of the hereditary cells, I want to give an outline of some observations I made about ten years ago, and which have recently been confirmed by Beard. Very early in the development of one of the California viviparous fishes certain cells apparently lose their interest in the development. They undergo very little change, while the rest of the cells are busily engaged in multiplying and forming themselves into the various organs of the young fish. These cells become shifted somewhat and probably engage in active migrations. Late in the development they again begin to divide and ultimately give

rise to the reproductive cells of the new individual. Not all reach this fate; a certain number are apparently lost in their migrations, and their late history could not be followed. So much seems certain—that none of the cells which became segregated from the rest so early ever became anything but reproductive cells, and that in no case do other cells ever become reproductive cells. The shortest route observed between reproductive cells in the new individual and the egg from which it developed did not exceed fifteen cell divisions. If the divisions had been continuous at the rate of division frequently seen in fish eggs all of them could have taken place in a day or two. Since the last generation of cells are really part of the new generation of individuals the time between the beginning of development and the completion of provisions for the next might have been but one or two days.

Into the question of the origin of heredity and the hereditary power of the reproductive cells I can not go at this time. Suffice it to say that I consider the hereditary power of the reproductive cells the result of a division of labor, just as the high contractile powers of the muscle cells is the result of a division of labor.*

It is evident from what has gone before that we can not say that the individual became alive at any given point. Each individual is part and parcel of many individuals who struggled and fought and aspired, who lived, and, above all, succeeded. The fact that he is, is proof positive that, as far as his ancestry is concerned, he deserves to be. He has always been alive since the creation of his remotest ancestor. There has never been a death in the direct line of his ancestry, and he forms a link in a chain that is potentially endless and, in so far he is, through his offspring, physically potentially immortal.

* That the reproductive cells never develop into anything but reproductive cells ought not to continue to confuse us, in the face of the fact that nerve cells, for instance, never give rise to any other kind of cells and other cells are never converted into nerve cells. Even in the regeneration of a lost arm only those sorts of cells are regenerated which have representatives at the cut surface.

CHILDREN'S VOCABULARIES.

BY M. C. AND H. GALE,
UNIVERSITY OF MINNESOTA.

THE philological legend that the vocabulary of a workingman is only about 300 words* should show proof why it should not go the way of all legends when it is found that a child of two and a half or even two years uses by actual count from 600 to 800 different words in one day. Has anybody really estimated or counted the words used by a workingman; if so, what method has been used? A physician and father was asked to guess how many different words were used by our three children up to two and a half years of age, either in common or by any one of them. He gave vent to emphatic protests of incredulity when his guess of 'about 200' was met by the actual number of 2,170. And we ourselves have found several times that, after following a child about all day with pad and pencil and taking down all his talk for a waking day till we were almost exhausted, when we then tried to make an estimate of the words used we have only come to within a quarter to a half of the right number. This illusive underestimation of a child's vocabulary is so universal that it can only be corrected by cataloguing, indexing and actually counting the words thus recorded for a whole day. In the following table are given the different words and the total number of words used by two of our children on the day they were each two and a half years old:

	Different words.		Total words.	
	2 (boy).	3 (girl).	2 (boy).	3 (girl).
Nouns	369	307	3367	2168
Verbs	189	165	2200	2048
Adjectives	83	79	729	1327
Adverbs	42	38	1314	1031
Interjections	8	8	113	198
Pronouns	27	15	678	761
Prepositions	21	14	636	405
Articles and Conjunctions	14	3	253	54
Totals	751	629	9290	8992

It is interesting to find from the complete tables† that of the 751

* See e. g. Max Müller: 'Science of Language,' First Series, 1870. "Now we are told on good authority, by a country clergyman, that some of the laborers in this parish had not 300 words in their vocabulary" (p. 226).

† See the authors' complete vocabularies, tables and discussion in their article 'The vocabularies of three children in one family to two and a half years of age,' 'Psychological Studies,' edited by Harlow Gale.

different words used by 2 (b.), 479 or 64 per cent. were used in the first five hours or half of the day.

Such a record does not by any means include all the words which it would be possible for a child to use in one day, could it come into contact with its entire little world of experience by playing all its plays, looking at all its books, going on all its occasional visits, seeing all its acquaintances, living through all the days of the week and seasons of the year—that would involve almost its entire vocabulary up to that date. These two children had used respectively, up to two and a half years, 1,432 and 1,308 different words, almost all of which constituted their still usable vocabulary. So that on these days they used only about half of the words they might have used. When a child's world of named things is smaller it will naturally use a larger proportion of its vocabulary on any one day. For instance, the eighty different words used by 3 (g.) at the beginning of the twentieth month were 96 per cent. of the vocabulary up to that day, but by the next month this proportion had dropped to 60 per cent. and in subsequent months varied from 54 per cent. to 43 per cent.

These children we believe to be but slightly, if at all, above the average child in the use of language. As an example of what a reputedly talkative child can do, we took the words used on his second birthday by Carl Andrist (whose father was instructor in French in the University of Minnesota); he used 803 different words.

Most of the records of children's vocabularies hitherto published have been gross underestimates, chiefly, we think, from two causes. In the first place, the estimate has almost always been made on the first or only child; for the enthusiasm for child study or psychology usually breaks out with the advent of the wonderful first child and lessens as this novelty wears away and heavier domestic cares with the second child discourage scientific ardor. But the later children have an advantage in learning much from contact with the older child. Thus our first child used only 400 words at two years, and 769 at two and a half years, that is, about half as many as the second or third child. Of three other published records of two children in the same family, two cases show a much slighter increase while one shows a decrease.

The second cause of the underestimation of a child's vocabulary is the use of unreliable methods. Even the almost constant presence of the mother with the child, and her daily noting of the new words it uses from the beginning of speech to the two or two and a half year limit, we found insufficient. For when in the case of the second child we also followed the child about and made a complete record, we found that the former method had failed to note many of the commonest words. We followed the third child through eight complete days, on the first of months 20, 21, 22, 23, 24, 25, 28 and 31; and, on checking

these words off with the daily noted new words, we found we should have missed some 250 words had we used only the method of noting new words. Thus any attempt to write out a child's vocabulary from memory or from spasmodic observations is utterly untrustworthy. So in spite of the extreme cases of children's use of words (from 25 to 1,100 at two years in the published cases), the average of 257 for the dozen children reported in Tracy's 'Psychology of Childhood,' pp. 142–144, seems only from a half to a third of the correct amount. For, even if we allow these to have been all cases of first children, the absence of any description of the method makes it probable that the easier and less complete methods were used. For the average of the first eight summaries of vocabularies at two years in Preyer ('Seele des Kindes,' 4te Aufl. 1895, S., 378) is 419, to which our first child's record corresponds. The child studied by Prof. Humphrey's thorough, though in some ways questionable, dictionary method had a vocabulary of 1,121 words. The child studied by G. Deville's method had a vocabulary of 739 words, which corresponds almost exactly with our younger children's records of 729 and 741. If then an average child at two years uses from 400 to 800 words, can we believe without some real evidence that any adult uses only the fabled 300?

The total number of words used on one day is to many people even more astonishing than the number of different words. For the child's energy represented in the production of 8,992 or 9,290 words is something relatively enormous. Would that this child energy could be expressed in figures! But here again some idea of what a speech 'record' is, can be obtained from the case of the above Carl A., who used on his second birthday—*i. e.*, when six months younger than our children—a total of 10,507 words!

In the number of repetitions of a single word one gets a measure, too, of the energy used; as on finding that our 2 (b.) used his own name 'Sammy' 1,057 times on one day (as subject, object and possessive, in place of the personal pronouns); while 3 (g.) used her favorite 'little' 660 times, 'that' 609 times and the aggressive ego words, 'I,' 'me' and 'my' 970 times.

Sammy,	1057	want,	204	some,	134
Papa,	350	see,	128	no,	292
Mama,	193	going,	124	yes,	104
Dick,	148	don't,	123	now,	151
Hilde,	62	go,	97	there,	134
boy,	45	get,	88	down,	105
bed,	42	put,	86	here,	100
house,	41	will,	79	that,	226
water,	34	did,	66	this,	116
		was,	61	in,	145
		have,	56	to,	147
		take.	55		

These comparative frequencies in the words used are an interesting index of the interests of the child, as well as of its energy. The preceding list gives those used most often by 2 (b.) on his two and a half year day:

Such a list shows the child's interests centered egoistically, and naturally, too, around his primitive struggle for existence. The aggressive want, go, get, put, will, have and take; the offensive don't, 'the everlasting no,' always taking precedence of the submissive yes; the demonstrating that, this, there, here, in and to—all show the natural pleasure-pain life in its immediate expression in ceaseless activity and in its conflict with the environment. The social instincts, however, appear in the more frequent use of his parents and sisters' names than of those of novel objects or objects for play; sympathy and approbation are shown by the use of see and some.

The important rôle played by the great activity of the child has been pointed out by Tracy (*ibid.*, pp. 146–148) in the child's use of a much larger proportion of verbs than the adult. The full record of a child's talk for a day gives a vivid and fascinating picture of this intense activity; the following scenes give fair samples. In her first play for the day with her doll, about three quarters of an hour after waking and before breakfast, 3 (g.) kept up the following stream:

"My little baby, my little baby. Momsie, Momsie, jiggle my little baby, jiggle my little baby. Please put that little pillow in, put that little pillow in —little pillow in. I did put. Just little tiny bit, little tiny bit,—little, little, little. Going take nightgown off. Safety pin, safety pin. Put that on bed. Going put that on, going put little pillow way. Please help me put my little baby's sleeves in. I call that my little baby. Why I—I—I? Try pin. Can't pin. Why write that way? Don't want my pillow,—want that pillow,—want—. Where that little baby sleep on my pillow? (Repeated) Why do just like that way? That bed spread lie on. (Repeated) Little baby,—cover legs. (Sings) Sweet little baby, sweet little baby,—Oh little baby, Oh little baby, Oh little baby, Oh little baby. Put that,—that bed spread little baby lie on,—have bed spread. Go right off. I going put my hands on that. Try make that stick together,—stick together; try make that stick together,—go together all nice. My little baby can't lie. What?—what? I used my—away back on Mamma's bed. Can't tell Hilsie that. My baby got two little shoes, two little stockings on. (Repeated) Can't take off. My poor little baby got go bed, got stay in bed. Got little neck, little neck, cunning little neck,—little neck. Please unpin that safety-pin, Momsie. My little baby not very well,—have stay in bed. No,—my little baby's nightgown,—that Grandma made (latter four times)—other Mama made me,—that Emma made me, that Emma made me. That Mama crochet, Mama crochet other one—other one. Hasie have that one (repeated twice)—that one. My little baby have sleep on, —where my little pillow? Got little chin. Why do that way? Got no nightgown. Play with little safety pin." (She then changed off to another doll.)

Of course the above was interrupted by some talk from other members of the family, but we tried to leave the child to its own activity

and spontaneous talk as much as possible. The following extract shows some of the different interests and activities due to sex. After his dinner at noon 2 (b.) began thus:

"Papa come upstairs and build with Sammy. Fix Sammy big fid(dle). S. will fix big one. S. want only—S. want Mama, one lady and one man. Oh Anna, S. see Bannie (made-up word). No, no, S. going to build little house for children. No wood—build with stone ones. No, S. want these. Put those in closet. S. want new (blocks). P. get some. Little P. get little S. Want some. No, S. will let S. S. going make pretty nice fairy houses. This going be little house down here, so can't get out. This tiny one can't get out,—get out. and get in. And that down there,—that there down beside and that, that side-arch. S. going to build nice, nice fairy house. Mama, when P. was little P. did hump, hump (laughing). Yes. S. thought he was Bannie, Bannie. (Pause playing with stone blocks alone). S. has to finish with these blocks. S. need old block—S. need old block. No, no, no, that little boy,—little boy. He going to go thro here. That S. mat. This does take all block. There P. big fid. S. don't see P. big fid. S. have to play,—have to play. S. have to put P. big fid,—P. Fiedelbogen. Yes. What this? S. want,—Hilde, H. H. (the four months' sister getting into his things). This little boy S. will give H. S. want that whip. S. going to get green Decke. Don't put Dick baby on (repeated). Little boy,—No, No,—S. want that little boy. H. did take little boy. Is'nt something to eat, H. No, No, but S. want,—H., H., H., want. Take H. H. don't want. This for H. S. can suck. Oh, there baby,—isn't down on floor. Take H.,—take H. Don't take,—here boy, here boy. Oh, some (nonsense syllables). Yes. Mama now S. Oh, here was hat. S. found hat,—S. found boy hat. Shan't we, P.? No, S. won't come up till P. come up. S. got block lean over. P. now come up. M., don't get on S. block. S. got blocks lean over. P. build with S. P. build fountain-house. S. have to build. P. long one, P. Now P. build with S. P., now S. P. know those go down there,—belong. No, S. will put arch up there. P. build with those. Put other arch up there. P. build with S. Now take this block and build down there,—now put across there. H.,—why, why, H! Take that H. P. now take this. P. now,—Oh, build P. No, No, No, that arch down here. No, No,—Oh, S. will give H. rubber doll. There H. Now P. sit down,—H. got rubber doll."

It is astonishing how this activity keeps up to the end of the day and how the child struggles against fatigue and sleepiness. After having looked at his Brownie book in bed awhile S. was laid down by his mother to be sung to sleep as usual and the gas was turned down. Whereat he said:

"S. can't see—S. can't see. P. now give S. some more paper to write on, two more and that will be all. Sammylein, Hildelein, Mamalein, Dicklein, and that will be all. S. can't see. (Repeated five times and seven Nos.) Yes, S. want drink. Now P. drink some,—now S. want 'nother drink. Now don't write M. S. is'nt getting tired, This Water Baby. Why? Go way up to that corner. S. don't want to. S. is'nt sleepy. S. got jelly glass at S. house. M., don't turn down gas, don't, don't don't. Where P. go? No, No. (Finally weakening he says) S. want go S. bed. S. want green Decke. S. want S. pictures. M. sing some Schub(ert). Was this right way? No, this was wrong way. M., this right way? (Adjusting his beloved green Decke) This

right,—Yes. M., S. want those two pieces paper,—give S. some paper. S. have to roll up. M. cover S. Where P.? Where P.? M., where P.? M. sing loud. M. lie down on P. bed,"

when the Männlein suddenly fell off to sleep.

How considerably the range of a child's interests can vary even in substantially the same environment can be seen by a comparison of the entire vocabularies of our three children. For out of the 2,170 different words used by some one of the three up to two and a half years of age, less than a quarter, 489, were used by all; while 2 (b.) used 480 and 3 (g.) used 586 words that were not used by either of the other children. The varying interests in these cases are partly due to the difference in sex. But in the case of Professor Holden's two girls, whom he expressly says were exposed to surroundings as similar as was possible, we find at two years of age 246 words in common, while the older had used 241 and the younger 154 exclusively.* These wide individual differences in the stock of words children use seem to us on examining the complete vocabularies in chronological order to be much better accounted for by the varying pleasure-pains or interests of the children than by the oft-quoted law of the ease of utterance.†

For though the stock in common is on the whole the easier and the individual variations are toward the harder, yet the short words with their easier initial or imitative sounds seem to be used because of their necessity or interest to the child's life, as, *e. g.*, the early words baby, cow, Papa, Mama, book, horse, dog, bottle, water, doll, pin, mittens; burn, see, take, want, eat, wash; pretty, hot, dirty, warm, broken, clean, sticky, another, there, off, away, quickly; good-bye, hurrah, peek-a-boo, etc., etc. The growth of language in the race has brought it about that the words most necessary to the child's life are the shorter and easier sounds. Thus the child uses them first because of their interest and serviceableness, and not because of their ease. So glancing down the chronological columns of our children's vocabularies,

* Holden: 'On the Vocabularies of Children under Two Years of Age,' *Trans. Amer. Philological Assn.*, Vol. 8, 1877, pp. 58–68.

† See Schultze, 'Die Sprache des Kindes' (1880), S. 27, for the use of this principle in the sounds used by the child for words. But Holden had already applied this principle to the words which the child successively used and thus made up his vocabulary. "I am inclined to take it as a result of my inquiry that the ease of pronunciation, far more than the complexity of the idea, determines the adoption of the word" (ibid. p. 60). But of this principle Humphrey said: "Although it had some influence before the child was one year old, when she was two, it had ceased to have any effect whatever. She had, by that time, adopted certain substitutes for letters which she could not pronounce, and words containing these letters she employed as freely as if the substitutes had been the correct sounds" (ibid., p. 7). For Preyer's arguments against the principle in both its applications to the sounds and to the real words see his pp. 367, 373 and 374.

one can see how the compound words came into use later on together with the finer specialization, shown also in the more exact adverbs, prepositions, conjunctions, etc.

Thus, too, many equally easy words come to be used much later when they become useful or interesting, as mat, muff, people, joke, note, lace, veil, care, screw, bone, gas, glue, guess, give, fill, feed, tell, buy, shine, scrub, sure, like and soft. On the other hand, long hard words are used when the child's interests need them, used, however, in the modified shape of the nearest imitative sound the child can make or of some original substitute word. Thus they associated some sound which served as a word for nigger-book, handkerchief, petticoat, toboggan, umbrella, Brille, hammock, Brightwood, university, perfumery, Bauchknopf, apple-sauce, rocking-chair, dein ist mein Herz, chimney-sweep, Pantoffeln, peppermint-candy, waste-paper basket, Miss Haversham, David Copperfield, Thomas Orchestra, Beethoven, Brahms, button-hole scissors, magnifying glass, Kohlpechrabenschwarzermohr (in which 2 (b.) only left out the two syllables en and er); telephone, vaccinate, be reposed, collapse, Headerei (to be carried on one's shoulders, originated themselves from Washerei), kitzeln, remember, disturb; comfortable, precious, old-fashioned; day after to-morrow, guten Morgen, guten Abend, auf Wiedersehen.

We believe then that the acquisition of words by a child is mainly accounted for by the psychological laws of pleasure-pain, viz.: (1) the biological law that whatever is favorable or more immediately beneficial to our organism is pleasurable and that the harmful is painful; (2) between these extreme limits things are further differentiated as pleasurable or painful by being associated with things already differentiated by the biological law, and this principle of association comes indirectly under (1); (3) by the habit or custom principle whereby we come to have pleasure in anything long-continued about us—supposing it is not so immediately harmful as to kill us in the process of adaptation.

Words then are simply the tools whereby the child gets more pleasures and avoids more pains. And the number of these words is normally limited only by the pleasure-pains which are of sufficient intensity to make the motor connections for speaking the words. We have many observations showing how this association of the sound with the thing was made without any apparent attention to the sound; so that when the child's pleasure-pain interest in the thing was enough for it to want to use the word, out it popped without any previous trial or practice. If the child merely lives in an environment where the words are heard or—later on—seen in books, the words get themselves ready for use when needed.

MESCAL: A STUDY OF A DIVINE PLANT.

By HAVELOCK ELLIS.

I.

MESCAL (*Anhalonium Lewinii*) belongs to the group of plants which in various parts of the world have been intimately connected with religion and have received the honors due to divine beings. This group may indeed be said to be large, but mescal—on account of the special appeal to the supernatural which its peculiar properties make—belongs to the innermost circle of such plants. It is or has been venerated by the Indians of many tribes over a very large region in Northern, Central and Eastern Mexico, in New Mexico, in Texas and in Indian Territory, each tribe having its own name for the plant—mescal, hikori, peyote, kamaba, etc.* Botanically it is a cactus, belonging to the special and little known group of the Melocacteæ; there are in the group some six or seven Anhalonia; they all grow in inaccessible spots on high and rocky peaks, and have only in recent years become known to science. The plant most nearly allied to the *Anhalonium Lewinii* is the *A. Williamsii*, from which is obtained the alkaloid pellotin, lately found of therapeutic value as a hypnotic. Mescal buttons (as from their shape the dried tops of *A. Lewinii* are locally known) are somewhat brittle discs some two or three centimeters in diameter and partially covered by a hairy cushion. Lewin and Henning in 1885 first described this cactus and made experiments on animals with it, from which Lewin concluded that it is 'intensely poisonous,' resembling strychnine in its action, and by its lethal action standing apart from all other *Cacteæ*. This opinion probably rendered investigators of mescal cautious, and little further progress was made in our knowledge until 1894, when Mr. John Mooney, agent among the Indians, who had read a paper on this subject before the Washington Anthropological Society three years earlier, brought to the United States Bureau of Ethnology a large supply of mescal buttons which were entrusted to Professor Prentiss and Dr. Morgan, of Columbian University for physiological investigation.

* I retain the name mescal by which the plant first became known. It has, however, the disadvantage of being identical with the name of an intoxicating drink, prepared from one or more species of *Agave*, with which it has no connection whatever.

II.

At this point it may be interesting to consider briefly the sacred rites with which the Indians have surrounded the mescal plant. These rites have been vaguely known for a very long time and were referred to by early travelers, like Hernandez and Sahagun. Father Ortega, on account of its hallucinatory properties, named it *Raiz diabolica,* devil's root.

The first reliable account of its use in modern times was given by Mr. Mooney from his experience of the Kiowa Indians on the Kiowa Reservation in Indian Territory. The religious ceremonies of these Indians usually take place on Saturday night; the men, having obtained a supply of the drug which is brought by traders from Mexico, seat themselves in a circle round a large camp fire within the tent. After prayer, the leader hands each man four buttons. One of these, freed from the tuft of hairs, is put into the mouth, thoroughly softened, ejected into the palm of the hand, rolled into a bolus and swallowed. Ten or twelve buttons are thus taken at intervals between sundown and 3 A.M., with the accompaniment of occasional prayers and rites. Throughout the ceremony the camp-fire is kept burning brightly and attendants maintain a continual beating of drums. The Indians sit quietly throughout, from sundown to noon of the next day, and as the effect wears off they get up and go about their work, without experiencing depression or unpleasant after-effects. On the day following they abstain, from ritual reasons, from using salt with their food. These and similar rites have become the chief religion of the tribes of the southern plain, to such an extent that the Christian missionaries, unable to grapple with the mescal cult by spiritual weapons, fell back on the secular arm and induced the government authorities at Washington to prohibit mescal under severe penalties. Nevertheless its use still persists.

Although the propaganda of the mescal cult among the Indians of the United States has thus been highly successful, it is fairly clear that much of its primitive religious significance has here been lost. We may understand how this is when we know that the Kiowa Indians are immigrants from the south; they come from the Rio Grande, and it is from the Rio Grande that they still obtain their mescal. Mexico is the chief home alike of the mescal plant and of the mescal rites in their primitive purity. It is to Mexico that we have to turn to realize their primitive significance.

As used by the Indians of the Nayarit Sierra in the province of Xalisco, mescal (or peyote, as it is here commonly called) has been described by Diguet.* Mescal is regarded by these Indians as a food of

* Léon Diguet, *Nouvelles archives des missions scientifiques,* Vol. IX., 1899, pp. 621–625.

even higher order than maize, for while maize is merely the food of the body, mescal is the food of the soul. It is indeed the supreme food, and on that account is offered to the gods. Like maize, mescal has tutelary deities and a special goddess. Its psychic manifestations are considered a supernatural grace bringing man into relation with the gods; while in moderation it enables men to face the greatest fatigues and to bear hunger and thirst for five days, that is during the fast prescribed by the laws of Majakuagy. It is said that when Majakuagy was engaged in preaching his doctrines he and his disciples had to flee from persecution. In the course of his flight he broke his food vessels near San Luis Potosi, and the gods in mercy changed the fragments into mescal. The Indians only gather it in October, just before the dry season; it is said that it is only at this time that it contains its active properties. The third maize feast, which takes place at the beginning of October, is regarded as a prelude to the mescal festival and dances. An expedition is organized to the spot near San Luis Potosi, where the prophet's utensils were transformed into mescal, to gather the sacred plant. This expedition takes a month; those who lead it march in front, reciting or chanting prayers; the others follow with the pack-animals to carry the harvest. A few days before reaching the holy spot the members of the expedition practise a rigorous fast. They also perform a sort of public penance with expiation. As they return, there is great rejoicing in all the villages through which they pass, and mescal is offered on the altars and fragments given to every person met. Sufficient is reserved for the great festivals, and the rest is sold to those who took no part in the expedition.

The Huichol Indians, who occupy part of the territory covered by Diguet's investigations, have been carefully investigated as regards their religious symbolism by Dr. Lumholtz, who touches on the mescal (or, as it is here called, hikuli) cult.* He states that the expedition to obtain the plant goes to a place near the mining town of Real Catorce in October, but that the great festival only takes place in January. Abstinence from sexual intercourse is part of the cult, and it is noted that the use of the plant temporarily removes all sexual desire. The balance of the body is said to be maintained better than usual, and under its influence men walk fearlessly on the edge of precipices, and endure hunger, thirst and fatigue to an incredible extent. Lumholtz states that the festival is connected with the god of fire. We may account for this by the luminous nature of the visions caused by mescal and by the influence of a blazing fire in stimulating those visions.

The same author, in the course of an account of 'Tarahumari Dances and Plant-Worship' † has described the cult of mescal among

* Carl Lumholtz, *Memoirs of the American Museum of Natural History*, Vol. III., Anthropology, II., 1900.

† *Scribner's Magazine*, Oct., 1894.

an allied Indian tribe who call it hikori and worship it as a god. This account furnishes a few supplementary details to Diguet's narrative of the expedition. We are told that as the Indians approach the plants they display every sign of veneration, uncovering their heads. Before gathering them they cense themselves with copal incense. They dig out the cactus with great care, so as not to hurt it, and women and boys are not allowed to approach the god. The plants are kept in jars in caves, and offerings of food and drink made to them. Even Chiutian Indians regard hikori as coequal with their own divinity and make the sign of the cross in its presence. At all important festivals hikori is made into a drink and consumed by the medicine men, and certain selected Indians partake of it, singing invocations to hikori to grant a 'beautiful intoxication.' A rasping noise is made with sticks, while men and women dance, the sexes separately, a picturesque and fantastic dance, the women in white petticoats and tunics, before those who are under the influence of the god.

III.

We have now to consider what are those special virtues which have caused this insignificant little cactus, hidden away among almost inaccessible rocks, to be surrounded by so splendid a halo of veneration.

The first really scientific attempt to ascertain the nature of the peculiar effects of this drug on the human organism was made by Professor Prentiss and Dr. Morgan in their investigation, already mentioned,* of the mescal buttons obtained by Mr. Mooney among the Kiowa Indians. These observers administered the drug, in what I should consider extremely large doses (in one case as many as seven buttons), to several subjects whose symptoms were noted and their color visions briefly described. These investigators made no observations on themselves. In the following year, however, Dr. Weir Mitchell, attracted by their account of the effect of the drug, obtained some of the extract from them and made an experiment on himself, taking a large dose. Dr. Weir Mitchell describes himself as a good subject for visions, and his vivid and elaborate account of his experiences, as read before the American Neurological Society,† furnished the first really full and instructive description of the artificial paradise of mescal. In the early part of the next year, having been greatly interested by Dr. Weir Mitchell's experience, and thinking that this drug might help to throw light on various matters which I was trying to account for, I succeeded in obtaining a supply of mescal buttons in England and experimented on myself. As these observations, the first made outside America on the psychic effects of mescal, covered the same ground as Dr. Weir Mitchell's, while at the same time revealing new classes of

* *Therapeutic Gazette*, September 16, 1895.

† Reprinted in the *British Medical Journal*, December 5, 1896.

phenomena which had not been noted by previous observers, it may be worth while to record them in full, as fairly typical of those vision-producing properties which procured for this plant its divine honors.*

The experiment took place on Good Friday, 1897, when I was entirely alone in quiet chambers in the Temple, the most peaceful spot in central London. I made a double infusion or decoction of three mescal buttons (a single infusion is inert) and drank this, in three doses, at intervals of an hour, beginning at 2:30 P.M., two hours after a light lunch. I had not touched alcohol or smoked during the day. The following notes are reproduced, with trifling omissions, exactly as written, during the course of the experiment.

"The most noteworthy, almost immediate, result of the first dose was that a headache which for some hours had shown a tendency to aggravation was somewhat relieved. At 3 began to feel drowsy. At 3:30 took another third of the infusion. My headache was speedily still further lightened, and I now felt a certain consciousness of energy and intellectual power. No color or other visual phenomena appeared, however, even when eyes were closed for several minutes. No obvious increase of knee-jerk, though I seemed to be conscious of a certain heightening of muscular irritability as when one has been without sleep for an unusual time. Some gastric discomfort now made itself felt, but was relieved (at 4 o'clock) by eating a few biscuits. At this time, for the first time, there was a distinct lowering of pulse by some 6 or 8 beats. At 4:30 took the remaining portion of the infusion. At this period, except for a very slight frontal headache and a faint sensation of nausea, no abnormal phenomena had yet appeared, and I was feeling on the whole better than before I began the experiment. At 5 I felt slightly faint, so that it was difficult to concentrate my attention while reading and I lay down on a couch; the pulse was still lower (48) but no visual phenomena could be detected. At 5:45 while lying down reading I noticed (what Weir Mitchell noticed) that a pale violet shadow floated over the page around the point on which my eyes were fixed. Some little time earlier I had noticed that objects not in the direct line of vision, such as my hand holding the book, frequently tended to become obtrusive, and as it were heightened in color, monstrous and enlarged. At 6 the prevailing feeling was one of slight faintness with some muscular unsteadiness; there was no marked discomfort (except slight nausea); the headache had almost gone. No

* I published a somewhat briefer account of this experiment in 'Mescal: a New Artificial Paradise,' *Contemporary Review*, January, 1898. This paper also contains the interesting results of an experiment on an artist friend; further remarks were published in 'A Note on Mescal Intoxication,' *Lancet*, June 5, 1897. These papers attracted the attention of Dr. Walter Dixon, who made many experiments on himself and has published the results in an interesting article in the *Journal of Physiology*, September, 1899.

further visual phenomena except that it seemed that on closing the eyes after-images were marked and persistent. It may also be said that for some time previously, although no color visions came, the play of light and shade always seen with closed eyes seemed more marked than usual, and *suggested* pictures which were not really seen.

"6:15. I should take more buttons in solid form, but refrain from doing so in consequence of the faintness which makes me disinclined to do more than make these notes. Also the thought of taking more of the drug and the sight of the glass produces a feeling of nausea. The blue-black color of the ink as I write seems unusually brilliant and the shadows on my left on the verge of the visual field seem unusually violet.

"6:40. Pulse now, lying down, is about 60. When lying with eyes closed I am more conscious than before of visions on the curtain of the eyelid; but they are vague and confused, the whole of the field seeming crowded with them, and even when definite images are seen they are not recognizable, but are of the same character as the images produced by the kaleidoscope—symmetrical groupings of spiked objects. Violet shadows are still conspicuous, and now also I see what some little time earlier I seemed faintly to see—occasional distinct green shadows on the outskirts of the visual field, while a green-toned newspaper lying on the floor, whenever I glanced at it, always seems unusually green.

"7:00. It is now dark, and chancing to glance out at the window for a moment and then close my eyes I was surprised at the astonishingly bright vision of light left in my eyes, a positive after-image. All objects seen not in the direct line of vision have a tendency to look startlingly large and prominent.

"Before 7:30, when lying with closed eyes, the visions had become much distincter, but still quite indescribable, mostly a vast field of golden jewels studded with red and green stones and ever changing and full of delight. And moreover all the air round me seemed at one moment to be flushed with vague perfume—producing with the visions a delicious effect. All feelings of discomfort have now quite vanished, except only a slight feeling of faintness showing itself by tremors in hands, etc.

"8.00. The chief character of the visions is their indescribableness; sometimes, however, they are like clusters of jewels—some bright and sparkling, others with a dull rich brilliance. Again they resemble a vast collection of the glistering, iridescent, fibrous wings of gorgeous insects. But the main impression is that they are constantly approaching and constantly eluding the semblance of known things. The human face is the only known form that is sometimes momentarily caught, or perhaps merely suggested.

"8:30. [*Written with pencil.*] Pulse now much higher (72 in

sitting position). Muscular incoordination is so considerable that it is very difficult to use a pen, but still easy to write with a pencil.

"I find that it is easily possible to see the visions when lying down in a dark room with open eyes. (Weir Mitchell could not do this.) Sometimes the vision seems to be of a vast hollow vessel into the polished interior of which one gazes while the hue rapidly changes on its mother-of-pearl surface. The objects seen are very often extremely definite; the remarkable point is that they are always novel. There has been all along apparent hyperæsthesia to all sensory impressions.

"9:10. I had to break off as I cannot write for long at a time. The visions continue as brilliantly as ever: I think I see them better in a room lighted by fire than in a dark room. I have seen thick glorious fields of jewels which spring into forms like flowers beneath my view and then seem to turn into gorgeous butterfly-like forms. When I speak my voice seems strange to me and certainly sounds hoarse.

"As I write (by electric light) vague thin color washes seem to lie on the paper, especially a golden yellow, and even the pencil seems to make somewhat golden-tinged marks. My hands seen in indirect vision seem strange, bronzed, scaled, flushed with red. Except for slight nausea I am feeling well, my head perfectly well, though when watching the visions I once noticed slight right frontal pain. The chief inconvenience is decidedly the motor incoordination. It involves inability to fix attention long; but otherwise intellect is perfectly clear.

"9:40. [*Written with pen.*] I am now going to bed. Visions continue; I feel well, except for slight nausea when I move and the motor weakness. [*What follows was written on the next morning.*] Before going to bed I drank some hot water with a little wine in it, but took nothing to eat. On undressing I was struck by the red, scaly, bronzed or pigmented appearance of my feet, hands and limbs when I was not directly looking at them. After going to bed the nausea entirely disappeared, not to reappear, and except for thoracic oppression and occasional sighing there was no discomfort. But there was not the slightest drowsiness. I think, however, that the visions might easily have blended into dream visions but that I was kept awake by a certain consciousness of faintness and by auditory hyperæsthesia. I was keenly receptive—as I had been all along—to sounds, and whenever I seemed about to fall asleep I was startled either by the exaggerated reverberation in my head of some distant street sound or else by the mental image (not hallucination) of a loud sound. At a later stage there was some ringing in the ear. There were also some slight twitchings of the larger muscles of the limbs. Before going to bed I had ascertained that there was marked exaggeration of the knee-jerk, and the pupils were dilated. I felt hot; the skin was dry, the kidneys active.

"Meanwhile the visions continued with but little diminution of

brilliancy, and the same perpetual novelty. Some new kind of effect was perpetually appearing in the field of vision; sometimes there was swift movement, sometimes dull somber richness of color, sometimes glitter and sparkle, once a startling rush of flashes that seemed to approach me. Usually there was a combination of rich dark color with jewel-like spots of brilliant color. Every conceivable color and tint seemed to appear at one time or another (Weir Mitchell never saw blue). Sometimes the different varieties of one color, as of red, would spring up in turn—scarlet, crimson, pink, etc. But, in spite of the immense profusion of objects, there was always a certain parsimony and esthetic value in the colors presented. They were always associated with form, and seldom appeared in large masses of color; if they did the color was of very delicate tone. I was struck not only by the brilliancy, delicacy and variety of the colors, but by the great variety and loveliness of texture which they presented—fibrous, waxen, polished, dull, glowing, veined, semi-transparent, etc. The glowing (jewel-like) and the fibrous (insect-wing) textures were perhaps the most prevalent. Although the effects were novel, they often vaguely recalled known objects—exquisite porcelain, elaborate sweetmeats, Maori architecture, Moorish windows. But in all these cases the objects grew and changed beneath my gaze without any reference to the characteristics of those real things of which they vaguely reminded me. I tried to influence their course but with very little success. It seemed that colors could to some extent be called forth but I could not evoke the simplest image by an act of will.

"On the whole, if I had to describe the visions in one word, I should say that they were living arabesques. There was generally a certain incomplete tendency to symmetry, the effect being somewhat as if the underlying mechanism consisted of a large number of polished facets acting as mirrors. It constantly happened that the same image was repeated over a large part of the field, though this holds good mainly of the forms, for in the colors there would still remain all sorts of delicious varieties. Thus at a moment when uniformly jewelled flowers seemed to be springing up and extending all over the field of vision, the flowers still showed every variety of delicate tone and tint.

"Unlike Weir Mitchell, who could not see the visions with open eyes even in the darkest room, I could see them in the dark with almost equal facility when my eyes were open, though they were not of equal brilliancy. After observing them in the dark for some hours, I became a little tired of them and turned on the gas. I then found that I was able to study a new aspect of these visual phenomena. The gas jet (a common flickering burner) seemed to burn with great brilliance, sending out waves of light which expanded and contracted enormously. I was even more impressed by the shadows which were in

all directions heightened by flushes of red, green and especially violet. The whole place became vivid and beautiful and the tone and texture of the whitewashed but not very white ceiling was immensely improved. The difference between the room as I saw it then and the appearance it usually presents was the difference one may often observe between the picture of a room and the actual room. The shadows I saw were the shadows that the artist put in, and that are not visible in the actual object under ordinary conditions of casual inspection. At the same time shadows chased each other across the walls, never becoming actual visions.

"I wished to ascertain how the subdued and steady electric light could influence the phenomena, and passed into the next room. Here the rich shadows which were evidently largely due to the stimulus of the flickering light were not obtrusive. But I observed that whatever I gazed at seem to show a tendency to wave or pulsate. If I looked at the matting on the floor it showed a singular richness of texture, thick and felted, with a tendency to rise in little waves. These effects were apparently due to the play of heightened shadows on the outskirts of the visual field. In the same way a closed door seemed to be ajar, from the heightening of the shadows in the interspaces.

"I returned to bed still experiencing the same phenomena though in a less degree, and now for the first time there was a tendency for human figures to appear, fantastic and Chinese in character. There were vague hallucinations of smell, sometimes distinct recurrence of the freshly prepared mescal infusion; these olfactory impressions were pleasurable, I think because they involved deep inspirations, and thus relieved the respiratory oppression.

"At 3:30 A.M. I felt that the phenomena were diminishing and was able to settle down to sleep. When I awoke two hours later, after a peaceful and dreamless sleep, there was a slight headache and the visions were still present with closed eyes, though they were now in somber colors, brown and black. I slept again for an hour or so and rose at the usual time feeling by no means tired, and with an excellent appetite; except for a slight headache which passed off in the course of the morning, I felt none the worse but rather the better for my experiment. The only after-effect was a slightly hyperæsthetic vision for colored objects (as at the beginning of the experiment), lasting for a day or so, and more especially noticeable as regards blue, so that a familiar notice-board in the Strand with dark-blue background was much more conspicuous and intensely blue than usual."

IV.

The experiment just described may be regarded as fairly typical of the effects of mescal in an ordinarily healthy subject, so far as my

observations extend. There are, however, very wide individual variations in the effects of the drug, as have been made clear by subsequent experiments which I have made on other persons. It may, therefore, be of interest to present another experiment for the sake of comparison. In this case the subject was not under my own immediate observation; I should not myself, indeed, have given him mescal at all, knowing that in such a case the experience would certainly not be altogether pleasant. The subject was an art-student, 26 years of age and 6 feet in height, a Highlander on the father's side, and a Lowlander on the mother's, presenting the type of the red-haired, beak-nosed Highlander. Though never ill, he is never in good condition, muscles flabby, skin clammy, pulse liable to be weak and intermittent, without reserve of mental or physical energy. He had severe rheumatism ten years previously. He is lazy and drinks and smokes to excess. He gives the impression of a man of splendid physical race, who has somehow not reached the perfection of his type. Altogether, so far as mescal is concerned, I should regard him as an unlikely subject for what the Indian would call a 'beautiful intoxication.' But the experiment which I give in the words of the very good observer who conducted it is not on that account the less interesting.

"The first dose was administered, after a fair meal, at 4:30 P.M. No nausea was at any time experienced. Pulse 96.

"5:00 P.M. The pulse was 86.

"5:30 P.M. The pulse was 62, flaccid and compressible, with a perceptible second beat, and rather intermittent. The subject had been lying in the veranda of the bungalow since 4:30 P.M. The second dose was now given.

"5:45 P.M. The pulse was 60, and remained at 60, except during exertion, for the next twenty hours. The pulsations were now occurring in a strongly staccato fashion. There was no perceptible second beat, and the pulse was not so compressible.

"6:00 P.M. The pulse was no longer staccato, but distinctly intermittent. It was, however, stronger, and but little affected by holding the wrist above the head.

"6:30 P.M. The third dose was given at 6:30, and the subject came indoors, and was wrapped up in a chair facing the open door, and looking out to sea. A deep sudden breath now caused a marked acceleration in the heart's action, and rising from a lying to a sitting posture sent up the pulse from 60 to 80, for a space of ten seconds or so.

"6:45 P.M. A feeling, neither pleasant nor unpleasant, of general lassitude and indifference, and a slight sensation of rigidity in the backs of the fingers when extended. The same feeling was present in a less degree all over the body, giving the subject the impression that the motor nerves were becoming partially paralyzed. Otherwise the subject was perfectly comfortable, though somewhat weak and lethargic.

"7:00 P.M. The pulse was alarmingly intermittent. There was often a pause of two seconds between beats. However, the subject was quite unaware of the fact, and perfectly comfortable.

"8:00 P.M. The subject complained of difficulty in breathing, as though a tight bandage were tied over the left side. The pulse was now almost, and sometimes quite, imperceptible. The arms became weak; in a few minutes they became absolutely paralyzed. The subject began to be a little scared. However, in about ten minutes the loss of power passed away, and he became perfectly comfortable, though disinclined to move a finger.

"8:45 P.M. The sea suddenly turned purple and tilted up to the eaves of the veranda, and instantly regained its normal aspect. The victim was not particularly excited at this sight; indeed, throughout the experiment I was struck by the very matter-of-fact way in which he received the various visions, I myself being far more keenly interested in them. The legs now became partially paralyzed for a few minutes. There was no other symptom whatever till 8:45 P.M., when very indefinite stationary spots of purple and blue-green were seen on the beach at a distance of fifteen or twenty feet. They gradually assumed the shape of rather conventionalized thistle-heads, some purple and some emerald. For a moment the shingle beach appeared to be turning into a bed of flowers, but they quickly faded away. When I went out and struck a match before the bungalow the flowers suddenly reappeared. Whenever a match was struck they became more vivid. It was now twilight and when the flowers appeared the beach became brighter.

"I now lit the lamp and placed it by the subject. The thistles had faded away. Suddenly the sea—which was gray—turned green, and became covered with symmetrically arranged spots of violet, which rotated on their axes and passed off to the right. There were three bathing-machines half way down the shingle, and the spots passed behind them.

"I now turned down the lamp. The shingle instantly became a bed of blue flowers; some unknown little plant which produced a short spire of blue blossoms, and a few green blades. I asked the subject to direct me to one spire which was higher than the others, and trod on it, when it disappeared. I turned up the lamp; the flowers disappeared.

"The subject now saw a large cutter about half a mile from shore, which sailed rapidly along and passed behind the bathing machines. He made a sketch of it as it approached, to give me the relative proportions of the cutter and the machines, and then described it as close in. As a matter of fact there was a small cutter about a mile off shore, and about one tenth the size of his sketch.

"9:25 P.M. On the beach, where the flowers had been seen before,

a head like the Cheshire Cat appeared. It was vague, except for the smile. Presently it developed a body and legs, and became a lynx, with no feet, and eyes like glowing opals. It danced gravely round in a circle. Having inquired as to its exact position, I went out and kicked it. It vanished.

"The subject now saw, in the wake of the moon, which was now shining brightly, a boat containing two men fishing, with a light. I could see the men only with the telescope. Handing the subject the telescope, he said that he saw the boat three times as large without the glass. He now came out and leaned on the rail of the veranda. A cloud over the moon appeared to him an oared galley, five times the diameter of the moon. The oars were moving at the rate of 30 strokes to the minute.

"10:15 P.M. The galley having disappeared, the subject sat down inside the door again. A creature with a pointed nose and sharp ears popped its head constantly round the corner of the door. As the pulse was again imperceptible I administered a pint of strong coffee.

"10:45 P.M. A beautiful miniature Eastern city appeared, on the beach about twelve feet away. It was lit, apparently, by the sun; there were walls, citadels, mosques, minarets, houses, etc., all white, interspersed with green foliage. It was very compact, standing high above the walls, and about six feet in diameter. After some five or ten minutes an enormous tortoise, with a Greek key pattern in metal round the periphery of the carapace, walked against the city and right through it when it disappeared, and the tortoise with it.

"Shortly afterwards a vast horde of little black woolly animals, rather like black guinea-pigs with astrachan coats and glow-worms for eyes, poured up over the pebble ridge from the sea, and disported themselves over the beach, which was quite covered with them. After pouring up for a minute or two they vanished into thin air. Their motion was like that of a swarm of maggots discovered in turning over a dead animal. This was the last vision. The subject expressed a desire for a very large meal, ate a small one, went to bed, immediately slept a dreamless sleep, and was for two days very languid and weak, with a feeble and depressed pulse, and occasional palpitation. He will on no account try the experiment again.

"The most remarkable feature of the visions was that they all had 'a local habitation and a name.' They all appeared out of doors, most of them on the ground at a distance of twelve feet or so; they did not move when the head or eyes were turned, but kept exactly in their place. The visions were seen with either eye indifferently; with the eyes closed nothing was seen. Mechanical pressure on the eye-balls had no effect. At one period of the experiment the muscles of the eyes became relaxed, so that the subject saw near objects slightly doubled."

V.

It may be seen from the two experiments which I have described in some fullness that, in general character, the physical and psychic manifestations of mescal somewhat recall those produced by haschisch, the most famous and typical of the 'artificial Paradises' which man has found for himself. No other drug, indeed, can be said to approach so nearly to haschisch in its effects. They are alike in the variability of their effects on different individuals and in the difficulty of obtaining a reliable preparation.* They both slow the heart, tending in some cases to produce intermittence, and both affect the respiration. They both produce muscular weakness and incoordination, exaggerate the knee-jerk and dilate the pupils. They both, moreover, possess the same vision-producing properties. I cannot speak from personal experience on this point, but one of my subjects, a poet who has paid much attention to the methods of generating visions, assures me that in his experience the virtues of the two drugs are about equal and that he has no preference for haschisch over mescal.

While there are thus marked and fundamental resemblances between mescal and haschisch, there also appear to be numerous points of difference. On the whole it may be said that mescal has a more restricted, a less generalized action than haschisch. In some of the early accounts of haschisch, which may now almost be said to be classic, great stress was laid on its exuberant motor manifestations, the uncontrollable antics, and the loss of all sense of time. These manifestations are much less conspicuous, and often do not appear at all, in the later accounts of haschisch, so that they are evidently not essential.

Under mescal, so far as I have been able to observe, they seldom appear. Mescal may at one stage produce a sense of well-being, vigor and intellectual lucidity, but there is no actual motor exhilaration, or loss of self-control, usually no mental failure at any point, except that when the influence is strongest attention may be impaired, so that one realizes when under mescal how much attention is a matter of muscular coordination. The action of mescal on the motor system is to depress, so that there is a tendency to tremulousness of the muscles which feel weak, and it seems to the subject that he must exert more than usual care

* Haschisch is said to vary in accordance with season, as well as with the district in which the hemp is obtained. The Indians believe that mescal is only active at one season of the year. I found one supply that reached me to be almost or quite inert, and it is possible that it was gathered out of season.

† The resemblances between haschisch and mescal come out most clearly in the latest and most reliable investigations, see, *e. g.*, W. E. Dixon, 'The Pharmacology of Cannabis Indica,' *British Medical Journal*, November 11, 1899, and E. B. Delabarre, 'Report on the Effects of Cannabis Indica,' *Psychological Review*, March, 1899. The latter is only a brief summary, but Professor Delabarre informs me that he hopes to publish a full account of his investigations.

to prevent himself from staggering and more than usual energy to perform even the simplest action. This may affect space-relations and one of my subjects found that in lifting a cup to his lips the distance traversed seemed very much more than usual; the same subject found that his ideas of time seemed to be disturbed, but on testing him with the watch his estimates were found to be fairly accurate.

The positive and active manifestations of mescal are always mainly if not entirely on the sensory side, and the motor weakness and sense of lassitude which is often present only throw the subject of mescal intoxication more absolutely at the mercy of the waves of unfamiliar sensory impetus which strike him from every side. Every sense is affected: apart from the various visionary influences, sounds become unfamiliar and abnormally acute, the sense of smell is stimulated or olfactory hallucinations may occur, the simplest food seems to possess an added relish, while there are vague skin sensations, and to the sense of touch the body seems as unfamiliar as everything else has become. I have elsewhere remarked, in illustration of the peculiar effects of this drug, that mescal seems to introduce us into the world in which Wordsworth lived or sought to live. The 'trailing clouds of glory,' the tendency to invest the very simplest things with an atmosphere of beauty, a 'light that never was on sea or land,' the new vision of even 'the simplest flower that blows,' all the special traits of Wordsworth's peculiar poetic vision correspond as exactly as possible to the actual and effortless experiences of the subject of mescal.

It should be added that a sense of well-being is not an essential part of these sensory manifestations. In this respect mescal is entirely unlike those drugs of which alcohol is the supreme type. Under the influence of a moderate dose of alcohol the specific senses are not obviously affected at all, but there is a vague and massive consciousness of emotional well-being, a sense of satisfaction tending to a conviction that 'all's well with the world.' Alcohol has a dulling influence on sensory activity and on the intellectual centers; and it may indeed be said that for the brain-worker whatever value the moderate use of alcohol may possess chiefly lies in the fact that after brain-work is over it helps to soothe undue brain-activity. Mescal, on the other hand, is not mainly emotional in its effects but mainly sensory and it leaves the intellect almost unimpaired even in large doses. It is true that at one stage of mescal intoxication, and more especially in quite healthy persons, there is a feeling of well-being, and even of beatitude, accompanied by an illusory sense of quite unusual intellectual activity; but there is no stage of maudlin emotionality; on the whole there is a condition of fairly unimpaired and alert intellect, untiringly absorbed in the contemplation of the strange world of new sensory phenomena into which the subject has been introduced.

These phenomena are above all visual, and the intellectual character of mescal intoxication as compared with perhaps any other intoxication, seems connected with the fact that it is the most intellectual of the senses that is chiefly involved. The visual effects of mescal may be of very various character, largely depending on the idiosyncrasy of the subject as well as on the degree of the intoxication. They vary from an exaggeration of the normal phenomena, producing a heightened play of light and shade and color, to visions seen on the curtain of the eyelid with closed eyes and with open eyes in the dark, up to actual localized hallucinations seen in broad daylight. It seems reasonable to suppose that the cerebral centers of vision are affected under mescal, and the occipital headache which occasionally follows supports such an assumption; a merely peripheral stimulation could scarcely suffice to account for such an orgy of vision. But at the same time I am convinced that the conditions produced in the eye itself are important factors in the production of the phenomena. Not only must we suppose that the retina, like all the sensory apparatus, has become hyperæsthetic, but the pupils are dilated, so widely dilated in one of my subjects that there was extreme photophobia. It is probably not without significance that in the other chief vision-producing drugs, such as haschisch and belladonna, the pupils are also dilated. It is evident that light can penetrate into the chamber of the eye with much more ease than usual. The Kiowa Indians sit round a fire during the nights on which the mescal rites are performed and I have found that the flicker of fire-light acting through the closed eyelids furnishes a very favorable condition for seeing the visions to advantage.

There is another characteristic of a large number of these visions (as indeed of many visions otherwise produced) which, it would seem, we must explain through peculiarities of the eye. I refer to what I have termed their kaleidoscopic character, the tendency to symmetrical grouping in the visual field of objects similar in shape, and harmonious, though not necessarily similar, in color, so that a kind of vision is produced such as we might attribute to an animal with faceted eyes. We might account for such a phenomenon by means of that irregular astigmatism, found more or less in normal eyes, which has been attributed to the fact that the crystalline lens is composed of many sections connected by radial sutures, or, more plausibly, with Shelford Bidwell, who has made some interesting experiments on this point, to the light passing through the coarse-meshed tissues of the eyes.* With perhaps still greater probability we might adopt the suggestion of Zehender† who in dealing with subjective visual perceptions would explain the strikingly regular polygonal figures which arise under various con-

* Shelford Bidwell, 'Multiple Vision,' *Nature*, April 13, 1899.

† *Klinische Monatsblatt für Augenheilkunde*, November, 1895.

ditions to the movements and displacements of retinal pigment grains in course of chemical decomposition.

There is another visual phenomenon caused by mescal, to which my attention was particularly attracted, since it appears to have been little noticed by previous observers, and which is of considerable interest because it may be brought into line with various phenomena which occur without the intervention of drugs. I refer to the play of shadowy color, and more especially the violet halos which are seen to play around and over objects and constitute, in my own case at all events, the earliest group of color phenomena seen under mescal. I have already described my impressions of this effect, and one of my subjects who saw the same phenomenon, describes it as 'a violet fringe, surrounding objects and tending to become flower-like.' It has been observed by many when passing over snow-covered regions, and especially by Alpine climbers, that moving objects, and more especially their own hands or garments, show a violet border.* Then we have the tendency to color vision (erythropsia or perhaps more strictly, or more usually, violet vision) to which the eye becomes liable after surgical removal of the crystalline lens. Once more there are the colors produced by the much discussed colorless 'spectrum top.' It seems to me that all these phenomena, and others that could be named, must be regarded as more or less allied. The first explanation offered for the earliest of them to be noted was that they are due to over-stimulation and exhaustion of the eye. Later inquirers have sought after a more precise mechanism for the phenomenon. Thus Dobrowolski in 1887, dealing with the erythropsia often occurring after removal of the lens, argues that a necessary condition is the dilatation of pupil produced by atropine, and that the color vision is really of the nature of a negative after-image of the rays that strike the eye. Fuchs, in 1896, who has dealt in an interesting manner with the erythropsia experienced on climbing snow-covered mountains (regarded by him as strictly a purple vision) finds that Dobrowolski's explanation is inadequate, and, while contenting himself with the theory of stimulation and fatigue for some of the phenomena, believes that the real explanation is to be found in a temporary visibility of the visual purple of the retina. Whatever the value of this explanation may be as applied to the whole group of phenomena, Fuchs more than any one helped to bring color-visions of this kind from the sphere of the pathological into the sphere of the normal. More recently still, Shelford Bidwell in 1897, when making some simple but ingenious experiments with the object of discovering the mechanism of the spectrum top, found that when a dark patch is

* This phenomenon was discussed in *Nature*, during May, 1897, some of those who described it assuming without question that it was an objective phenomenon.

suddenly formed upon a bright ground the patch appears to be momentarily surrounded by a blue border, and he accounts for this by the theory of a sympathetic affection of the red nerve fiber; when the light is suddenly cut off from a patch in a bright field, there occurs an insensitive reaction in the red fibers just outside the darkened patch, in virtue of which they cease for a short time to respond to the luminous stimulus, in sympathy with those inside the patch. The green and violet fibers, by continuing to respond uninterruptedly, give rise to the sensation of a blue border. Where highly competent experts fail to agree it would be rash to state any definite conclusions. It is difficult, however, not to believe that, whatever the precise retinal process may be, over-stimulation and fatigue certainly have very much to do in calling it into action. Associated with the violet halo, as we have found, there is a tendency under mescal, especially by the aid of a bright flickering light, for shadows generally to be variously colored, more especially (as in erythropsia and allied conditions) towards the outskirts of the visual field. Any one who will sit for a few minutes with his eyes directed on a sheet of white paper illuminated by bright sunlight will soon begin to see on a small scale a faint reproduction of the colored shadows seen under the influence of mescal. Here clearly we have a fatigue phenomenon due to over-stimulation by bright light, and precisely analogous to the after-images produced by looking at any excessively bright object. Under mescal we have a similar effect produced, not through the stimulation of unusually bright light, but by the unusually hyperæsthetic condition of the visual apparatus, due in part to the dilatation of the pupil and in part to the effect of mescal on the retina.

There is one other effect of this fascinating drug to which attention may finally be called. It has been pointed out that under mescal all the peripheral sense organs become highly irritable or hyperæsthetic. Not only is this so, but they are brought in a quite unusual degree into sympathy with each other. I found that casual stimulation of the skin at once heightened the brilliancy of the visions, or produced an impression of sound. One of my subjects, an artist, had a curious sensation of tasting colors, and another found that music had a delightful influence over the visual effects. This, and the fact that the Indians keep up a continual beating of drums during the time they are under mescal, led me to plan a further experiment on myself with mescal. I arranged that when the stream of visions was in full force a friend should play to me on the piano various pieces of a more or less progressive character which were unknown to me, at all events by name. I found that these pieces, more especially those which were somewhat uniform and monotonous, not only distinctly stimulated the visions, but influenced their character; and in about half the tests there was a

real resemblance, sometimes in a striking manner, between the prevailing nature of the visions and the name of the piece. This was especially the case as regards Schumann's music. It would be worth while to carry out further experiments along this line, and on a variety of people, preferably non-musical people. It may be added that under some circumstances music itself evokes a train of visual imagery. Heine has somewhere described in detail the imagery called up when listening to Berlioz's music, and in 'Florentine Nights' he describes, in the person of his hero, the elaborate imagery evoked on hearing Paganini play, and remarks: "You know my second sight, my gift of seeing at each tone a figure equivalent to the sound, and so Paganini with each stroke of his bow brought visible forms and situations before my eyes; he told me in melodious hieroglyphics all kinds of brilliant tales; he, as it were, made a magic lantern play its colored antics before me, he himself being the chief actor." It would seem that in Heine's case music produced actual visual imagery, as under the influence of mescal. In this connection I may recall an account of visual imagery, as seen at a concert, recorded by Dr. Robert MacDougall.*

One is tempted to ask by what process we should conceive to ourselves that the action of mescal works on the organism. I think it is not impossible to hazard such an explanation, provided that we avoid the risks attending undue precision in our explanations. We are justified, it seems to me, in supposing that mescal effects its peculiar actions by producing a kind of violent but temporary neurasthenia and cerebrasthenia. In other words, it rapidly overstimulates and exhausts the nervous and cerebral apparatus, more especially on the sensory side. It is true that such an explanation might be said to apply to the action of many drugs, including all those that are commonly called stimulants. The day has gone by when it could be supposed that a stimulant put anything into the system. It acts not by putting energy into the system but by taking it out, and so rapidly producing a state of fatigue. The careful experiments of Féré with the ergograph have lately shown that all sorts of sensory stimulants, acting on various senses and not necessarily involving the use of drugs, produce an immediate increase in the output of muscular work, but that no sensory stimulant of any kind will enable us to do a total amount of work equal to that we can achieve without stimulants, because the sudden rise of output is more than compensated by the subsequent fall. So that by the use of stimulants, so far as output of work is concerned, we not only draw on our capital,

* 'Music Imagery,' *Psychological Review*, September, 1898. The cases in which some definite appearance is regularly associated with the sound of each instrument belong to an allied though different class; a case of this kind is recorded in *Nature*, March 6, 1890. Here, we approach the best known group of 'secondary sensations.'

we actually dissipate and waste it. But the results of this kind of fatigue do not usually produce any condition comparable with neurasthenia; they do not, for instance, produce visions. In neurasthenic states there is, however, a tendency to visionary effects—colored vision, intolerance of light, photopsiae, persistence of retinal impressions, etc.—and, moreover, in all temporary conditions of nervous fatigue in otherwise fairly healthy people the same tendency to abnormal color effects with open eyes, and vague visions with closed eyes, is apt to show itself. I find that some persons, when very tired, see shadows as unusually violet, while kaleidoscopic visions and processions of figures and faces are also seen with closed eyes after fatiguing days. I have myself noted effects faintly recalling those produced by mescal after periods of unusual brain activity. On the border-land between sleeping and waking color-visions are also sometimes seen, and Mrs. Christine Ladd Franklin has stated that in falling asleep over a book she sees colored shadows, especially violet, floating over the page. It is noteworthy, further, that in various conditions of abnormal color-vision fatigue increases the brilliancy of the colors. The same tendency rules the association between music and visions. Heine was a somewhat neurotic subject who constantly complained of very severe headaches, and Mr. MacDougall, in describing the physical conditions under which he finds that visual imagery is liable to occur, describes a state approaching that produced by mescal: "In the earlier stages of fatigue, before the final condition has been approached, a period of cerebral excitement occurs, often accompanied by slight frontal headache, in which my mental imagery becomes more varied and concrete than normal. I feel an unusual brilliancy and fertility of suggestion; my mental scenery becomes less schematic and algebraic; comparisons and illustrations suggest themselves on every hand; thought proceeds by object images." It may be pointed out that neurasthenia is widely regarded as a condition of depression with irritability of the higher cerebral centers. Binswanger, indeed, in his book on the pathology of neurasthenia, considers the parallel between fatigue and neurasthenia as so close that he is inclined to regard the latter as nothing else than a prolonged condition of over-fatigue. In mescal intoxication we may be said to have a neurasthenia which is very limited, but is very sudden and swift. The sensorial apparatus is allowed to run violently down, and in healthy persons the accompanying acute metabolic activity produces the pleasurable feelings which usually accompany nervous activity. It is perhaps due to the swiftness of this process, and also to the good physical condition of the subject, that no unpleasant after-effects are usually experienced. I have noticed that the pleasant or unpleasant effects and after-effects of mescal may be quite accurately foretold from a knowledge of the subject's general health, and that the better his general

condition the less likely is he to experience any unpleasant results from taking mescal.

It was inevitable that an attempt should be made to drag mescal into the already overcrowded field of therapeutical agents. Curiously enough, the first affection which it was used to treat was neurasthenia, and the results were said to be good, but nothing further has been heard of it. In various quarters it has been suggested for use in insanity, and at Carmarthen Asylum Dr. Goodall, as he informs me, has made many trials with it, on melancholic and stuporose patients, pushing the drug eventually in large doses, but beyond dilatation of pupils and rapidity of heart action, the results were nil. I have myself never felt hopeful about mescal as a therapeutic agent, and though it is possible that of the various alkaloids obtained from it some may be found useful, it is not easy to see in what diseased conditions the crude drug itself is indicated. The fact that its best results are obtained in perfectly healthy individuals would alone counter-indicate its use as a remedial agent, and at present there seems no excuse whatever for thrusting it into the pharmacopœia.

The chief interest of mescal is for the physiologist and the psychologist.* It may be added that for every healthy person a single experience, at all events, of what mescal has to teach would be an educational advantage of no little value. As one of my subjects, who strongly feels this educational value of mescal though he has no wish to repeat the experience, remarks: "The connection between the normal condition of my body and my intelligence had broken—my body had become in a measure a stranger to my reason—so that on reasserting itself it seemed, with reference to my reason which had remained perfectly sane and alert, for a moment sufficiently unfamiliar for me to become conscious of its individual and peculiar character. It was as if I had unexpectedly attained an objective knowledge of my own personality." Thus it is that the Indians who raised this remarkable plant to divine rank, and dedicated to it a cult, have in some measure been justified, and even in civilization there remains some place for the rites of mescal.

* 'What an excellent use for a medical congress,' Mr. Francis Galton writes to me, 'to put one half of the members under mescal, and to make the other half observe them.'

INFECTIOUS DISEASES.

By ALFRED SPRINGER, Ph.D.,
CINCINNATI, OHIO.

INFECTIOUS diseases have devastated more homes than all wars combined, and a check to their ravages would be the greatest boon suffering mankind can hope to achieve.

These diseases are supposed to owe their origin to the activity of ferments, enzymes, sporozoa or other ultra-microscopical organisms, consequently they must have some reactions in common with other phenomena depending upon the same agencies.

If true scientific reasoning is based upon inductive methods, namely, 'the endeavor from the much which is observable to arrive at a little which may be verified and is indubitable' then truly our knowledge of ferments is very meager—in fact practically everything we know is deduced from observing the alcoholic yeast ferments, and this for the following reasons: First, they have been employed for many ages. Second, they are larger than the other ferments. Third, they can be studied without jeopardizing fellowmen. Fourth, their chemical effects can be traced in the laboratory, qualitatively and quantitatively, and last, but not least, their study is not beset with those difficulties which immediately present themselves when effects are produced upon higher differentiated types such as man.

I shall only call attention to such properties which undoubtedly many pathogenic bacteria hold in common with them, namely, we know that these ferments multiply with exceeding rapidity—that they can withstand great ranges of temperature and many chemicals poisonous to man—that they can accommodate themselves to abnormal conditions and remain dormant until suitable conditions again arise and that by their immense numbers much organic material is destroyed. We know, on the other hand, that these ferments have their enemies which can either suppress them entirely or to such an extent as to make them harmless. We know that the introduction of other ferments in the same medium, making use of one of their essential nutrients, may cause a total cessation of their activity—we know that their own excreta or similar products act as poisons upon them. We also know that ferments and enzymes are selective in their foods, probably not from volition, but for reasons of food assimilation.

It is a well-known fact that but an imponderable quantity of a specific ferment is required to start fermentation and this, owing to

reproduction, increases in a geometrical proportion, so that in a comparatively short time the whole mass is attacked. Thus a small amount of yeast will start the dissociation of thousands of gallons of a mash—the bacteria, in a septic tank, derived from the human digestive tracts, liquefy in twelve hours all the sewage of a household, including the paper and other cellulose matter. Pathogenic germs, in media such as nutrient gelatine, agar-agar, blood serum, etc., also develop quite rapidly; nevertheless the progress of infectious diseases is comparatively slow and frequently localized.

Since many pathogenic germs are present in the air we breathe, in the water we drink, and in the soil we come in contact with, infectious diseases seemingly ought constantly prevail; this not being the case, it has been assumed that the system itself under normal conditions can withstand their attack. Predisposition, on the other hand, betokens a weakened system, *i. e.*, decreased vitality, or one in which the way for the entrance of the germs has been paved. From this it may be concluded that the so-called specific disease germs generally present are no more dangerous than the predisposing media. Immunity can be obtained either by avoiding the pathogenic germs or the predisposing cause. At present means are suggested to isolate the consumptive and destroy the intermediate-bearing host, both in malaria and yellow fever. It is not even known whether other carriers equally dangerous exist.

The destruction of the predisposing cause certainly is more humane, and the one to be sought for. Unfortunately success has been limited to but few of the many diseases known to be of an infectious nature. Probably failure is largely due to ignorance of causes producing immunity, and in fact every theory so far advanced has been badly battered by numerous failures of substantiation.

Recent experiments indicate that specific ferments can only dissociate specific foods, *i. e.*, the assimilable ones for any one class of ferments do not constitute a wide range. Furthermore, it has been proved that micro-organisms can either be antagonistic to each other, *i. e.*, one can change some nutrient essential to the other's existence, or synergetic, where one is dependent upon the other for its food—and, in some cases, they may be indifferent where the food of the one is not that of the other.

Synergetic action plainly shows how limited is the dissociating power of micro-organisms. Thus an albuminoid is first converted into an ammonia compound by one class of ferments, a second class produces nitrites and a third nitrates. In the absence of the first, neither nitrites nor nitrates can be formed, and in the absence of the second no nitrate will appear. Still more striking—most exact experiments have shown that both ferments and enzymes cannot assimilate food chem-

ically and physically the same as some of their best nutrients—save in having opposite powers of rotation.

Taking into consideration that micro-organisms can withstand temperatures and chemicals fatal to man, the slow development of infectious diseases is most probably intimately connected with an insufficiency of assimilable food. This food it may be assumed can only be obtained by symbiosis either with other micro-organisms or products of cell activity in the system itself.

It is claimed that the *Anopheles* mosquito is the intermediate host of the human malaria and the *Culex* that of the bird, but not *vice versa*. These mosquitoes undoubtedly do not select the spores of their respective parasites and avoid the others, but there must exist conditions in the system of the respective mosquito which allow of the propagation of one kind and not the other—and these conditions, I take it, are food assimilable ones.

White mice are immune to splenic fever, other mice very susceptible. Since the blood of white mice is more alkaline than that of the others—and such blood when made less alkaline becomes a good medium for the cultivation of the anthrax bacillus—it has been claimed that the alkalinity produces the immunity. On the other hand it has been found that alkalies are not particularly harmful to the anthrax bacillus —therefore, it seems to me, that alkalinity, as such, is less of a factor than its consequent effects upon the nutrients of the bacillus.

Pasteur demonstrated that micro-organisms select one of two optical isomers, and Fischer proved that it is not only a question of optical antipodes in different sugars, but amongst a great number of geometrical forms few fulfil the requirements of the cells—furthermore he is of the opinion that many chemical processes in the system are affected by molecular geometry.

The albuminoids are the most important constituents of the living cells and since they are synthetically formed from the carbohydrates of the plants, Fischer believes that the geometrical structures of their molecules, as far as asymmetry is concerned, are essentially like those of the natural hexoses. Thus it seems that configuration plays a most important rôle in making food assimilable—be it in converting inactive into active modifications or *vice versa* or the production of one optical isomer instead of the other, or some other change of configuration, the consequence would be a different behavior toward the ferments, enzymes and sporozoa.

We now come to another feature which also may be of physiological interest, namely: the fact that the alkaloids largely used for therapeutical purposes, such as quinine, cinchonine, quinicine, conchinine, strychnine, brucine and morphia can, like micro-organisms, bi-part racemic forms. Thus cinchonine separates as salt from the inactive

modification insoluble: l-Tartaric acid; d-Methoxylsuccinic acid; d-Mandelic acid. *Penicillium glaucum* destroys: d-Tartaric acid; l-Æthoxysuccinic acid; l-Mandelic acid. Lewkowitch's schizomycetes destroy: l-Tartaric acid; d-Mandelic acid. Strychnine separates: l-Lactic acid; l-Æthoxysuccinic acid. Many other examples can be cited, the principal difference being that the alkaloids separate the insoluble optical isomer and the micro-organisms make use of one of the optical isomers to build up their own structure.

The bi-partic powers of the alkaloids are as limited as those of the micro-organisms; thus strychnine can bi-part lactic acid, cinchonine malic but not lactic acid, etc., and most likely two acids bi-parted by the same base have analogous configuration.

From these arguments, I take it that predisposition and immunity are intimately connected with stereo-chemical changes, *i. e.*, where the configuration, according to Fischer, of the nutrient, on the one hand, and the ferments, enzymes, sporozoa, etc., on the other, must be to each other as lock and key. Moreover, I believe that infectious diseases are not caused by any one class of ferments, but by many acting synergetically. In line with these results it strikes me that predisposition is a condition well suited to act synergetically when the missing ferment presents itself. Immunity, on the other hand, betokens the absence of a number of active synergetic ferments, owing to lack of requisite configurations.

While this suggestion may seem to offer one hazy hypothesis for another equally hazy, it opens a broader field for investigation, it admits of better explanations of observed results, and it agrees with our ideas that the demolition of complex organic materials, such as blood and the tissues, takes place step-like and not abruptly.

Surely some day physiological chemistry will be sufficiently powerful to shed its light through the mist now surrounding the so-called vital processes—clearly define the differences between the healthy and the disease-disturbed systems—teach us how to preserve the former and counteract the latter, by other than merely empirical methods.

When that day comes, infectious diseases like tuberculosis will no longer rob the stricken patient of all hope and cause him to be a constant menace, dreaded even by those who love him most dearly. When that day comes, parents no longer need be haunted by the fear that predisposition be transmitted to their children born and unborn.

THE PHYSIOLOGICAL EFFECTS OF ELECTRICALLY CHARGED MOLECULES.*

By Professor JACQUES LOEB,
UNIVERSITY OF CHICAGO.

FIVE years ago I published a series of papers on the physiological effects of the electric current which impressed upon me the long-known fact that the galvanic current is the most universal and effective stimulus for life phenomena. This fact suggested to me the idea that it should be possible to influence life phenomena just as universally and effectively by the electrically charged molecules—the ions—as we can influence them by the electric current. From that time on the whole working force of my laboratory was devoted to the investigation of the physiological effects of ions.

My first aim was to find out whether or not it is possible to alter the physiological properties of tissues by artificially changing the proportion of ions contained in these tissues. In this way originated the investigations on the effect of ions upon the absorption of water by muscles, the effects of ions upon the rhythmical contractions of muscles, and medusæ, the heart of the turtle, and the lymph hearts of the frogs, the rôle of ions in chemotropic phenomena and the influence of ions upon embryonic development, and the development of unfertilized eggs (artificial parthenogenesis). Those who have followed my work on artificial parthenogenesis may have noticed that from the start I aimed at bringing about artificial parthenogenesis through ions. It seemed to me that I could not find any better test for my idea that the electrically charged ions influence life phenomena most effectively than by causing unfertilized eggs to develop by slightly altering the proportion of ions contained in them. I believe that all these experiments proved what I expected they would prove, namely, that by slightly changing the proportion of ions in a tissue we can alter its physiological properties.

The next step taken consisted in proving that it was indeed the electrical character of the ion that determined its specific efficiency.

* 'Studies on the physiological effects of the valency and possibly the electrical charges of ions': Introduction and conclusion on theoretical considerations (the footnotes being omitted) of Part I. 'The toxic and antitoxic effects of ions as a function of their valency and possibly their electrical charge,' originally printed in the *American Journal of Physiology*. From the Hull Physiological Laboratory of the University of Chicago.

I succeeded in doing this three years ago. It was known that a frog's muscle gives rise to twitchings or rhythmical contractions when immersed in certain solutions. I showed that such contractions, occurred *only in solutions of electrolytes, and not in solutions of non-conductors* (distilled water, various sugars, glycerine, urea). Soon after I showed the same to be true also for the rhythmical contractions of the medusæ. From observations made in my laboratory, the same fact was shown to hold for the turtle's heart by Mr. Lingle, and for the lymph hearts of the frog by Miss Moore. I am confident that this fact will be proved universally.

In the physiology of the heart one frequently encounters the statement that calcium is the stimulus for the contraction of the heart. I had found that a muscle is able to twitch rhythmically when immersed in the solution of salts with a monovalent kation,—I obtained contractions in Na-, Li-, Rb-, and Cs-salts,—but that the addition of a small quantity of a bivalent kation—Ca, Mg, Sr, Ba, Be, Mn, Co—inhibits these rhythmical contractions. This seemed to be a direct contradiction to the statement that calcium salts are the 'cause' of the heart-beat. The significance of the calcium had to be looked for, then, in another direction. It was soon found that the muscle, the apex of the heart, and a medusa contract rhythmically in a pure sodium chloride solution, but that they soon come to a standstill. If, however, a trace of a soluble calcium salt is added to the sodium chloride solution, the contractions continue much longer. I concluded from this that the pure sodium chloride solution acts, in the long run, as a poison—that is to say, brings about definite but at present unknown physical changes in the protoplasm—but that a trace of a calcium salt annihilates this toxic action. The amount of calcium necessary for this antitoxic effect is of course much smaller than the amount necessary to inhibit the rhythmical contractions. Soon after I succeeded in demonstrating conclusively the poisonous effect of a pure sodium chloride solution, and the annihilation of this effect by calcium. The eggs of a marine fish (*Fundulus*) develop normally in sea-water, but they can develop just as well, as I had previously found, in distilled water. The addition of ions from the outside is consequently not necessary to the development of this animal. I found, now, that, if the freshly fertilized eggs of this fish are put into a pure sodium chloride solution having a concentration equal to the concentration of the sodium chloride in the sea-water (about $\frac{5}{8}$ *m*), not a single egg can develop into an embryo. If, however, a trace of a calcium salt is added to the sodium chloride solution, as many eggs develop and in just as normal a manner as in ordinary sea-water. The calcium ions in this case undoubtedly serve the purpose of annihilating the poisonous effects of a pure sodium chloride solution.

In the meantime I had become familiar with the brilliant experiments of Hardy upon the influence of ions and the galvanic current upon colloidal solutions. They indicated to me that the next step I had to take was to see whether or not the valency and the sign of the electrical charge of an ion determine its physiological effects. I suspected that the antitoxic effect of the calcium ion in the above-mentioned experiment was due to its electrical charge and decided to investigate in a more systematic way whether or not the sign and quantity of the electrical charge influence life phenomena. My experiments carried on at Woods Hole this summer showed conclusively that this is the case for the antitoxic effects of ions and probably for the production of rhythmical contractions through ions. It seems at least possible that it is true also for artificial parthenogenesis.

Theoretical Considerations.

1. We have to attempt to answer the question, How can the electrical charges of ions produce a toxic or antitoxic effect? The answer to this question must be preceded by the answer to the more general question, How can the electrical charges of ions as well as of an electric current influence life phenomena? The basis for the answer to this question will undoubtedly be found in the work of Hardy, as well as that of Bredig, on the rôle of the electrical charges of the particles in a colloidal solution. Hardy has shown that living protoplasm is to be considered as a colloidal solution, a hydrosol. Such hydrosols are suspensions of solid particles in a fluid (water). These particles are at the highest about 1,000 to 10,000 times as large as the dimension which the kinetic theory of gases assumes for the molecules. The forces which keep these particles in solution are of an electrical nature. There exists, according to Helmholtz and Quincke, a double electrical layer at the limit between particle and surrounding water.

When the colloidal particles have a positive charge, the surrounding particles of the water have an equal negative charge. It agrees with this assumption that the colloidal particles move under the influence of an electrical current in the same way as ions. They move to the anode when they carry a negative charge, and to the kathode when they carry a positive charge. Hardy has made it probable that these charges keep the particles in solution, inasmuch as through these charges they must repel each other. Hardy has shown that as soon as these charges are taken away from them the colloidal particles will no longer be held in suspension, but either fall down or rise to the surface. In this case the hydrosol is transformed into a hydrogel. These charges can either be taken away from them through the oppositely charged electrode of a battery, or through oppositely charged ions which easily give off their charge. Solutions whose colloidal

particles have a negative charge can be caused to coagulate (go into the gel stage) by one of two means: either by positively charged ions, or by the positive electrode of a battery. The coagulating effect of ions increases with their valency, and much more rapidly than the valency. The most valuable among Hardy's discoveries is the fact that in a solution of white of egg the colloidal particles can be rendered either positively or negatively electric by the addition of hydrogen or hydroxyl ions. When the neutral or isoelectric point is reached, the slightest change—one feels almost inclined to use the word 'stimulus'—is sufficient to transform the solution into a gel.

But long before the critical point of a colloidal solution is reached the variation in the charge of the colloidal particles alters their physical properties. An increase in their charge has the same effect as if the viscosity of the liquid were increased.

The bulk of our protoplasm consists of colloidal material, and the physical manifestations of life, such as muscular contractions and protoplasmic motions, and the innervations, are due to changes of the condition of these colloidal solutions. We now may be able to understand why the electrical current is the universal form of stimulation. The reason may be that the particles in colloidal solutions are electrically charged, and that every alteration of the charge of the particles will result in a process of innervation or a contraction or protoplasmic motion, etc. We likewise understand why the ions, on account of their electrical charges, are equally well capable of altering the physiological properties of the tissues, as the galvanic current.

But how can the ions cause toxic and antitoxic effects through their electrical charges? In my preliminary notice on these experiments which appeared in Pflüger's *Archiv* in November, 1901, I pointed out the possible relation of the electrical charges to the viscosity of the protoplasm. Phenomena of cell division are, as I believe with Bütschli and Quincke, phenomena of protoplasmic streaming. Such phenomena require, as Quincke has shown, a definite degree of viscosity. If the viscosity is too great, no protoplasmic motion is possible, and the same is true if the viscosity is too small. It may be possible that the toxic charges—presumably the negative one in the case of sodium salts—alter the viscosity of the protoplasm by either making it too liquid or too viscous, thus preventing the protoplasmic motions necessary for cell division or the muscular contraction. Small quantities of oppositely charged ions with a higher valency, which give off their charge sufficiently readily, will act as antitoxic substances.

2. The thermodynamical theory of life phenomena has utterly failed to show how the thermal energy produced through the splitting up and oxidation of foodstuffs can lead to muscular contraction. Engelmann's well-known attempt at an explanation is based on a physical impossi-

bility, in view of the fact that some muscles, especially those of the wings of insects, are capable of relaxing and contracting a large number of times in a second. The facts mentioned at the beginning of this paper point distinctly towards the possibility that part of the chemical energy in our body is transformed into electrical energy, or, in other terms, the ions formed in metabolism seem to play a rôle in the dynamics of life phenomena. From the facts mentioned in this paper we can see that these ions, or rather, their electrical charges, may be responsible for such physical manifestations of life as the muscular contractions and others. It remains to be explained how the electrical energy of the ions may be transformed into the mechanical energy produced by the contracting muscle. This will be discussed in the second paper, but I will point out here that I believe that the electrical energy of the ions is transformed into surface energy. It will now become necessary to pay more attention to the production of ions in metabolism than has been done before. The CO_3 and PO_4 ions, as well as the H ions, can no longer be considered as mere waste products of metabolism.

3. The fact that ions may act toxically through their electrical charges, and that ions with the opposite charge may act antitoxically, may open a new and very fertile field for pathology and therapeutics. As I have stated in previous papers, especially certain neuroses, and perhaps certain mental diseases, may now find their explanation. Two years ago I pointed out that we must realize the existence of physiologically balanced salt solutions, that means salt solutions in which the ions are so combined that the toxic effects of the one are counteracted by the antitoxic effects of some other ion. Any disturbance in the right proportion of monovalent ions and ions of higher valency must lead to more or less pronounced modifications of the life phenomena.

AN AFTERNOON AT CHELLES AND THE EARLIEST EVIDENCES OF HUMAN INDUSTRY IN FRANCE.

By Professor A. S. PACKARD, LL.D.,
BROWN UNIVERSITY.

THE earliest traces of human occupation in France and on the European continent occur at Chelles, near Paris. We have said the oldest on the continent, for apparently still older flint implements occur in England. We refer to the so-called 'Eoliths,' or plateau implements, found by Harrison, Prestwich and others in southern England.

The Chellean flint axes are still taken out of a bed of preglacial gravel in the sand pits of Chelles resting directly on the Eocene Tertiary clays. This deposit is overlaid by later paleolithic beds, containing worked flints of the age of the earlier cave-dwellers of Le Moustier, in the Dordogne, and called the Moustierian epoch. Directly above this layer, just below the surface of the soil, occur polished stone axes of the later or recent (Neolithic) Stone Age, and other remains of human industry of the time of the Swiss lake-dwellers, while in the swamps and loam are occasionally found Gallo-Roman antiquities, such as Gallic coins, serpentine axes, and bronzes of the time of the Antonines.

Relics of the French who immediately succeeded the Romans in France are also occasionally dug up. Clovis I. and Clovis II. built villas here, and the site of one of them still preserves the name of 'the royal palace.' The queens of these two Merovingian kings, Ste. Clotilde and Ste. Bathilde, founded a monastery near the royal villa.

Thus a single glance at the walls of the gravel pits near the town shows the successive steps in the history of the region—the different stages in Paleolithic times, as well as the Neolithic or recent Stone Age; so that here are revealed, as perhaps nowhere else so clearly, the overlap of prehistoric on historic times.

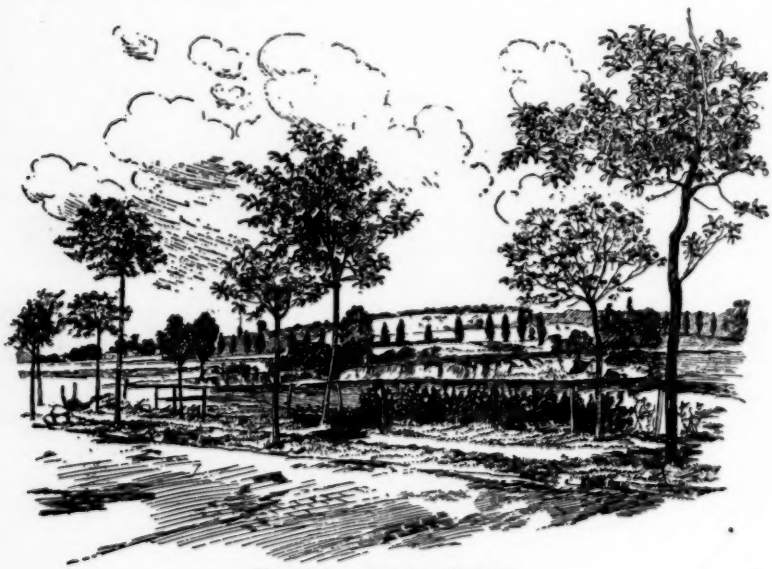
It is to be observed that the relics or traces of human occupation also occur in geological strata or beds of definite age, not in caves of somewhat uncertain age, and they are associated with the bones and teeth of quadrupeds, such as the elephant, rhinoceros, horse, deer, the cave bear, etc., all of extinct species.

Hence a visit to this classical locality on a serene though hot July afternoon, in a most attractive region and in most delightful company, was both interesting and memorable.

The pleasant town of Chelles with its outlying villas, gardens and

modest parks lies on the north bank of the Marne about twelve miles east of Paris. It is built on the southern slope of a low eminence, with a southern exposure.

Alighting from the train, and accompanied by Professor Paul Barbier, we drove to the house of the Abbé Alfred Bonno, to whom we had been referred as distinguished by his knowledge of the prehistoric archeology of Chelles and its neighborhood. We were most cordially met by the Abbé, and before accompanying us to the quarries he invited us to examine the large collection of prehistoric remains which was stored in the attic of his house. It comprised very full series of stone implements from the bottom to the top of the paleolithic, including



THE SAND-PITS NEAR CHELLES.

not only the Chellean and Acheulean, but also those of Moustierian age, up to the Magdalenian subdivisions, with some Solutrian lance-points. There were also numerous polished stone axes taken from the loam about the town, as well as Gallo-Roman bronze spear-heads, and finally iron weapons of war, as Chelles was once the center of the Merovingian kingdom. There were also fine knives of flint dug up from the gravels of the Fontainebleau forest. An examination, even if a hasty one, of such a rich local collection was the best possible preparation for our visit to the quarries.

We then drove to the neighborhood of the sand pits, walking to them from the end of the road, through the fields and by a shaded path, until we came out into an open space to the edge of the pits.

The accompanying figure gives a clear idea of the sequence of beds drawn from a photograph which we owe to the kindness of the Abbé Bonno.

These gravel quarries are excavated in the Pleistocene or Quaternary gravels and are situated on a plain between 125 and 140 feet in height

THE BEDS AT CHELLES, CONTAINING PREHISTORIC FLINTS, ETC.

above the sea, extending from Chelles eastward to the neighboring village of Brou. The strata underlying the fresh water or river-gravels are greenish clays or marls of marine origin and of Eocene Tertiary age. This marl contains gypsum or plaster of Paris, with crystals of

selenite, besides bones and teeth of the Eocene deer-like *Anoplotherium*, and of *Dinotherium*, an early forerunner of the elephant.

Upon this lower Tertiary marine bed rest the fresh water Quaternary beds, the series beginning with the lowest Pleistocene beds, passing through beds of supposed glacial origin containing transported pebbles, up into postglacial strata containing Neolithic implements.

The transition from the Tertiary formation is sudden. When the lowest Quaternary beds were deposited, the Eocene marl beds had been elevated, become dry land and exposed to the erosive action of the winds and rains. A long interval passed between the time of deposition of the Tertiary beds and the Pleistocene deposits which now cap them. It is to be observed that the later Tertiary formations (Oligocene, Miocene and Pliocene) are absent.

The Quaternary deposits at Chelles are divided into four distinct fresh water beds, each differing in age and in their materials, and as exposed by the workmen the whole series appears to be about 25 to 30 feet in thickness. They are as follows:

D, E. The lowest bed, that directly overlying the Eocene marl, consists of rolled pebbles and grayish sand, the mass being often cemented by calcareous infiltrations. This bed contains the Chellean implements. (What is apparently an upper division of this bed (*D*) is what the Abbé Bonno calls the Acheulean, and from it have been taken axes like those found at St. Acheul near Amiens.) In this lowest bed also occur the remains of *Elephas antiquus, Rhinoceros merckii,* etc.

C. A deposit, not forming a continuous bed, and only seen in places, of water worn coarse gravel and small pebbles derived from Tertiary gravels, and called by Bonno *'sables moyens.'* This is the red drift, *'diluvium rouge,'* of Ameghino. It abounds in rolled, broken, sometimes entire, Tertiary marine shells which have been brought by fresh-water streams probably from Lizy-sur-Ourcq and from Etrépilly a few miles to the northeastward, or perhaps from Soissons to the north (Bonno).

B. A second layer of drift or rolled and transported gravel, containing flint implements of the Moustierian epoch, and bones of the mammoth.

A. A thin bed of gray clay of the age of the Swiss Lake-dwellers, in which occur polished stone axes.

The chief center of interest is of course the lowest bed (*D, E*), that containing the worked flints. These are the celebrated Chellean axes, which are of various sizes, no two exactly alike, which were worked out by chipping from flint nodules, the flint being derived from the chalk deposits. These crude weapons were probably used in the chase or in battle, and were not mounted, but held in the hand. Almond-shaped, in the form of a 'coup de poing,' they were worked on both sides or

faces, showing a set of primary and secondary chippings or flakings. Their edges are sharp, not water-worn, and, as Ameghino states, they were evidently shaped by the early paleolithic workmen on the bed where they occur. Probably several hundred of these axes have been taken from these pits. Ameghino states that he possessed over a hundred of them.

With these axes sometimes occur long rude flakes ('lames'), knife-like, sharp on one edge, struck off from the flint core by percussion. No skin-scrapers (*racloirs* and *grattoirs*) or rude spear-points have ever occurred in these beds. No human bones or teeth have ever been found in these deposits, either here or at St. Acheul, and apparently nowhere else, unless we except the human molars claimed by Nehring to be of Chellean type. These are two very large molar teeth resembling in some respects those of the chimpanzee and found in the mid-Pleistocene drift of Taubach near Weimar.

At all events man as man lived here, and what manner of beasts were his contemporaries? They were in nearly every case representatives of species now extinct. Bones and teeth of the straight-tusked elephant (*Elephas antiquus*) and of the megarhine or big-nosed rhinoceros, are not infrequent; we obtained fragments from the workmen, and picked up some in the débris at the bottom of the pit.

The remains of other mammals are less common. Ameghino enumerates besides those mentioned, the bones and teeth of the hippopotamus, of a beaver-like rodent (*Trogontherium,* also found in the preglacial beds of St. Prest, Durfort, etc.), of an ox, of a horse (perhaps *Equus stenonis*), and an extinct deer different from the reindeer. This deer is probably the same as *Cervus belgrandi* found in beds of the same age and nature at Montreuil, where its bones are associated with the straight-tusked elephant (*E. antiquus*) and *Rhinoceros merckii.* Ameghino also found at Chelles two canine teeth of the cave bear. As to the numerous molars of the horse (we found two) Ameghino states that they differ from those of the modern horse (*Equus caballus*) frequently occurring in the later Quaternary and are allied to the Tertiary species called *Equus stenonis.* Since the date when his paper appeared Steno's horse has been referred to the lower Pleistocene, a time of transition to the Pliocene Tertiary, and most probably, according to Osborn, represented by the forest beds of Norfolk, England, and the equivalent beds of St. Prest, Durfort, and other localities in France. In fresh-water beds of this horizon occur also remains of the cave-bear, cave-hyaena, saber-toothed tiger, musk ox, *Hippopotamus, Rhinoceros etruscus, Trogontherium cuvieri,* of an otter, and of two species of elephant, *Elephas meridionalis,* supposed to have been the ancestor of the mammoth (*E. primigenius*) and *Elephas antiquus.*

These details may be dry enough to our readers, but they are of prime importance in relation with the question whether man originated before the Quaternary, either in France, or, as is perhaps more probable, migrated there from some Asiatic or African region in company with the hippopotamus, rhinoceros and other tropical forms which were his contemporaries.

Here might be mentioned the equivalent beds exposed in the sand-pits at Montreuil, which is nearer Paris, and just north of Vincennes. As stated by Ameghino, the deposits at this place are the same as at Chelles. The lowest beds are gray sands, without boulders, and rich in mammalian bones. Above lies a bed of large rounded pebbles, but it is sterile, or destitute of any but mere fragments; directly above is a bed of sand, this being capped by the red drift with boulders. The lowest beds present the same traces of denudation and of ancient erosion as observed in the corresponding beds at Chelles. No Chellean axes have been found at this quarry, at least the workmen were unacquainted with them, but Ameghino himself found in the lowest or preglacial bed two flint flakes, with a very pronounced bulb of percussion (*'concoide'*) which prove the former presence of man.

In the third bed (*B*), *i. e.*, that lying beneath, occur the true Moustierian implements which are entirely different in shape from the Chellean axe, being broadly triangular or pointed in outline, and only worked on one face, being flat on one side and convex on the other. In this interglacial bed occur the bones and teeth of the mammoth (*Elephas primigenius*) and this is the age of the cave-dwellers of the Spy or Neanderthal race, the age of the mammoth, of the *Rhinoceros tichorhinus,* the reindeer, musk ox, etc. With the Moustierian points occur flint knives, and also two new forms, the skin-scraper (*racloir*) and lance points. We see here traces of the immigration of subarctic mammals, showing that the climate was cooler than in the Chellean epoch, while the human race had either become modified, or had migrated hither from elsewhere, though these peculiar broad points do not, so far as we know, exist beyond the limits of France.

The same sequence is shown in the lowest beds at St. Acheul, near Amiens. The basal deposits, rich in Chellean almond-shaped implements contain at or below the depth of seven meters the remains of *Elephas antiquus;* at or below five meters *Hippopotamus amphibius,* while in the higher beds the straight-tusked elephant is succeeded by the mammoth, whose remains do not occur below the depth of three meters (Osborn).

Ameghino calls attention to a circumstance worthy of mention. As we have seen, flint axes of excellent workmanship occur in considerable numbers at the base of the lowest Quaternary beds lying directly upon the eroded surface of the Eocene Tertiary greenish marls.

So well are these implements made that we are forced to believe that this industry extended back to a still earlier period than the age of the beds in which these axes occur, and as he says, this fact 'constitutes for me the most weighty arguments that we can invoke in favor of the existence of man during the end of the Tertiary period.' Exhibiting to the members of the Anthropological Society the flints and teeth he had found, he showed that their edges were not water-worn, and that the flint axes had been abandoned by men where they were found. "Man, then, lived on the spot, and the instruments, at least in part, have also been worked out on the same ground. What proves this is that the little nuclei, like the two I exhibit, were found in the same bed. The teeth and bones of the mammals present no trace of having been water-worn. On the other hand, as the mammalian remains and the evidences of human workmanship are found at all the horizons of this lower bed, we are obliged to conclude that man inhabited this region almost continuously, or at least with very brief interruptions."*

Remains of man have been discovered in Kent County, England, and in Dorset in the high-level gravels, which are certainly preglacial, as they contain remains of *Elephas meridionalis* in beds regarded by Lyell as 'a patch of Pliocene gravel.' These beds were afterwards referred by Prestwich to the early Pleistocene. As Prestwich states, the base-line between the Pliocene and the lowest Pleistocene is somewhat arbitrary, and the two periods in England gradually merged into each other.

These beds were afterwards referred by Prestwich, certainly the best authority then living, to the early Pleistocene. As he claimed, the base line between the Pliocene and the lowest Pleistocene is somewhat indefinite, and the two periods in England gradually merged into each other. The beds in question, namely those in Kent and Dorset counties, England, were regarded by Prestwich as the English equivalent of the St. Prest (Eure et Loire) beds, situated about fifty miles southwest of Paris, and also of the so-called Pliocene beds of the Val d'Arno in Italy. These beds, as well as those at other places in France, *i. e.*, Durfort in Gard, and Malbattu and Peyrolles in the Auvergne (Puy-de-Dome), which also contain remains of *Elephas meridionalis,* are now regarded as 'transitional between Pliocene and Pleistocene with prevailing affinities on the latter side.† The climate of this transitional preglacial epoch, when the plateau man of Southern England chased the tropical or meridional elephant, and other beasts, such as tigers, hyaenas, rhinoceros and the hippopotamus, a mixed assemblage of

* 'Sur le gisement de Chelles,' *Bulletins de la Société d'Anthropologie* (3), iv., 1881, pp. 96–101.

† H. F. Osborn, 'Correlation between Tertiary Mammal Horizons of Europe and America,' *Annals New York Academy of Sciences,* xiii., 1900, pp. 1–72.

Asiatic and African forms, was mild, though somewhat cooler than that of the later Pliocene. It grew colder at the end when the glacial period was ushered in.

While of course the remains of man, or his flint tools, are to be looked for in the Pliocene beds of Europe, it is still possible that he was an immigrant from southeastern Asia, and shared in the migration of animal life which reached Europe from that region at the beginning of the Quaternary or Pleistocene.

It is now generally recognized that the 'missing link' or half ape, half man creature (*Pithecanthropus erectus*) of Java, whose skull (calvarium), femur and three molar teeth were discovered by Dubois in beds shown by him to be of Pliocene age, was the immediate precursor of man.

In the absence of any traces of man in the Tertiary beds of Europe may he not have, geologically speaking, suddenly appeared in Western Europe in company with *Elephas meridionalis*?

In his 'History of the European Fauna,' Scharff states that the genus *Elephas* makes its first appearance in the Upper Miocene of India.

"Our European *E. antiquus* is, according to Professor Zittel, probably identical with *E. armeniacus* of Asia Minor, while *E. meridionalis* agrees in all essential characters with the Indian *E. hysudricus*. The Indian and European species of fossil elephants altogether are very closely related, and the supposition that they all have had their original homes in the Oriental region offers, I think, no serious obstacle. The view of the European origin of the mammoth especially is open to very serious objections. It does not occur in any European Pliocene deposits, and could not therefore have originated in our continent until Pleistocene times."

It may be here stated that the mammoth (*Elephas primigenius*) is believed to be a descendant of *Elephas meridionalis*.

We may, then, provisionally at least, venture to suppose that the human descendants of the Java ape-man shared in this great wave of migration of tropical beasts, birds, insects, shells, etc., which at the end of the Pliocene or beginning of the Quaternary passed by way of Asia Minor and Greece into Europe, and peopled the plains and roamed through the forest lands of western Europe.

This view is supported by the fact that after the many years of research in the upper tertiary beds of Europe, no indubitable trace of flint tools of human workmanship or any other traces of human occupation have yet been discovered, while thousands of them, we speak within bounds, have been taken from the preglacial gravel beds of France and of England, which lie next above the Tertiary strata.

THE PROGRESS OF SCIENCE.

THE WILL OF CECIL RHODES.

THE bequest of Cecil Rhodes for education and the promotion of a good understanding between Great Britain and the United States follows very closely upon Mr. Carnegie's endowments of education in Scotland and of research in the United States. These three gifts, each of $10,000,000, are of such magnitude that they not only assure the accomplishment of vast plans for the general good, but also attract public attention and mold opinion in a way that is perhaps as beneficent as the direct results. Mr. Rhodes was misunderstood during his lifetime—he was called the 'Diamond King of South Africa,' a promoter of stock companies and an adventurer. Now his will is misunderstood in some quarters; it is said on the one hand to aim to aggrandize England at the cost of other nations, and, on the other hand, to be chimerical—a chapter from Rousseau's *Emile*. Rhodes almost ranks with Napoleon and Bismarck in his masterful personality, and in a certain straightforward lack of scrupulousness. While Napoleon subordinated all to his personal ambition and Bismarck was chiefly concerned with the aggrandizement of a dynasty, Rhodes devoted himself to building an empire, including in his projects, as his life in part and his will fully indicate, the welfare first of the British Empire, then of the Anglo-Saxon race, then of the Germanic nations and finally of the whole world. Both in his life and in the provisions of his will he was a dreamer and an idealist. But in his life he proved that he was a seer who could turn his visions into facts, and there is every reason to believe that his plans for the disposition of his fortune will actually accomplish the ends he had in view.

It was certainly a fine dream to bring together at Oxford young men from the colonies, from the United States and from Germany, selected for intellect and character, learning to esteem each other, carrying to all parts of the world common interests and a common culture. It would be intolerable if all our universities were Oxfords, but there is room in the world for one place that shall fully represent the traditional culture of the past, and Oxford possesses a unique fascination that seems to adapt it to the purpose planned. The more Oklahomian the young man sent to Oxford, the more will he profit and the more will Oxford itself profit. The students from the United States who have studied in Germany have brought the two countries close together, and the hundred American boys constantly at Oxford will surely make more intimate and cordial the relations between the two great Anglo-Saxon races.

Oxford is not a university for research, but a place for culture: the boys who are awarded the scholarships should be just from school, as Mr. Rhodes intended. His provisions for selecting them deserve quotation. The qualifications are to be:

First—His literary and scholastic attainments.

Second—His fondness for or success in manly outdoor sports, such as cricket, football, and the like.

Third—His qualities of manhood, such as truth, courage, devotion to duty, sympathy for and protection of the weak, kindliness, unselfishness and fellowship.

Fourth—His exhibition during school days of moral force of character and

instincts to lead and take interest in his schoolmates, for these latter attributes will likely in after life guide him to esteem the performance of public duties as his highest aim.

Marks for these four qualifications should be awarded somewhat in the following proportions: Four-tenths for the first, one-tenth for the second, three-tenths for the third and two-tenths for the fourth.

Marks for the several qualifications should be awarded independently—that is to say, marks for the first qualification by examination; for the second and third qualifications, respectively, by the ballot of fellow-students of the candidates, and for the fourth qualification by the headmasters of the schools, and the result of the awards, that is to say the marks obtained by each candidate for each qualification, should be added together and the successful student be the one who received the greatest number of marks, giving him the highest all-round qualification.

THE AMERICAN UNIVERSITY.

THE great educational endowments created by Mr. Rhodes, Mr. Carnegie and others naturally direct attention to our universities, and the question as to what they are accomplishing is asked on many sides. An optimistic answer is given in the last number of the *North American Review* by President Harper, of the University of Chicago, and a pessimistic answer in the last and preceding number of the *Forum* by Professor Ladd, of Yale University. Dr. Harper points out that the library and the laboratory occupy the places of honor in the university. He tells us that the laboratory for a single science should 'cost more than the entire college plant of the last generation.' The largeness of the cost of a modern university is rather attractive than otherwise to him: he has spoken of the need of a university with an endowment of fifty million dollars; and this does not, as a matter of fact, appear to be extravagant at a time when a manufacturing corporation may have a capital of a thousand million dollars. The making of men and the advancement of knowledge is after all a more important industry than the manufacture of steel. Dr. Harper is certainly right in maintaining that professional schools should be part of the university, and is probably right in urging the affiliation of colleges with one another and with the university. But he seems to be unduly optimistic and perhaps locally influenced in professing faith in the future of the denominational university. He says: "Whatever the state may do, the obligation which rests upon the churches is as strong and as serious as it has ever been in the past." But the church can never permanently compete with the state; the future belongs to the state university. Baptists may endow a university, but no one should endow a Baptist university.

The cheerful if somewhat material optimism of President Harper is preferable to the complaining tone adopted by Professor Ladd. He gives correctly the functions of a university: "(1) The highest mental and moral culture of its own students; (2) the advancement, by research and discovery, of science, scholarship and philosophy; (3) the diffusion, as from a center of light and influence, of the benefits of a liberal, genial and elevating culture"; but he thinks that "the institutions of the higher education in this country are worth all that they are costing . . . only if they are to be prepared to exercise all these three functions in a much more intelligent and effective fashion than at present." Now every one hopes that the American University will continually improve its methods of teaching, will increasingly contribute to the advancement of knowledge, and will more and more become the intellectual and moral center of the community; but it seems odd that a university professor should doubt whether a university is at present worth what it costs. All our universities together do not cost one tenth

as much as the sugar we eat, the beer we drink or the tobacco we smoke. The education of a single man who makes a scientific discovery with industrial applications pays back to the community the entire cost of his university since its establishment. And surely the moral and intellectual influence of the university is entirely incommensurate with its cost. But Professor Ladd believes that our political leaders 'are as good as the people who tolerate them deserve,' and that in general we are in a condition of 'degradation, social and moral,' so it is perhaps no wonder that he does not altogether approve of our universities.

THE AMERICAN PHILOSOPHICAL SOCIETY AND THE AMERICAN PHILOSOPHICAL ASSOCIATION.

IT is somewhat interesting to notice that at almost the same time last month, the American Philosophical Society, established in 1743, held a general meeting in Philadelphia, and a newly established American Philosophical Association held its first meeting in New York City. A hundred and fifty years ago all the sciences were parts of philosophy, and it was natural for a society established primarily for the promotion of useful knowledge to call itself a philosophical society. Now we have some twenty sciences, each maintaining a separate national society. The last of all the groups of special students to organize themselves is that of students of philosophy, and they not unnaturally take the name in which the American Philosophical Society has historic rights.

As a matter of fact students of philosophy have for some years met as a branch of the American Psychological Association, and it is gratifying that nearly a hundred teachers of philosophy in our colleges and universities have found it possible to organize a national society. It is also worthy of note that the Philosophical Association will meet next winter at Washington, in conjunction with the American Association for the Advancement of Science and its affiliated societies, thus indicating its intention to be a truly scientific society. There has certainly been a tendency for a branch of knowledge, when it became reasonably definite, to split off from philosophy, leaving to that discipline those subjects regarding which agreement is impossible. But students of philosophy are now finding a definite field that can be cultivated by scientific methods, whereas students of the special sciences discover the need of examining certain presuppositions that properly belong to philosophy. There is undoubtedly at present a *rapprochement* between philosophy and the sciences, of which the newly established Philosophical Association is a sign and to which it will contribute. The first meeting, held at Columbia University, was decidedly successful. Over forty members were present and some twenty papers were presented and discussed. Professor J. E. Creighton, of Cornell University, presided, and is succeeded in the chair by Professor A. T. Ormond, of Princeton University.

In the March issue of this Journal we published an article on the American Philosophical Society, established by Franklin and 'held in Philadelphia for the promotion of useful knowledge.' The oldest of American societies, it has for more than a century and a half maintained its activity and usefulness. The general meeting held last month in the old hall of the society brought together members from all parts of the country and a large and interesting program. There may be some question as to whether the Philosophical Society should undertake to retain the national character which it very properly assumed when first established, or whether the time has not now gone by when special papers on all the sciences can to advantage be presented on one program, but it is certain that the

social and other arrangements made in Philadelphia could scarcely be equalled in any other city. Philadelphia must share with Washington, New York, Boston, Chicago and other cities the honor of being one of our chief scientific centers, but its Philosophical Society still retains a certain preeminence.

SOCIETIES FOR THE SCIENTIFIC STUDY OF EDUCATION.

THE backwardness of education as a science is borne witness to by the lack of professional societies such as exist for other sciences. It is a sign of progress, therefore, that at the last meeting of the British Association an educational section was established and that the first meeting of an 'American Society for the Scientific Study of Education' met recently in connection with the meeting of the Department of Superintendence of the National Educational Association. At the same time and place there was held a conference of teachers of education in American colleges who considered steps toward formal organization and elected as chairman, Professor John Dewey, of Chicago University, and as secretary, Professor M. V. O'Shea, of the University of Wisconsin. Both these organizations seem likely to become more and more societies of experts in the scientific treatment of educational problems rather than of men of practical influence in the management of school systems, and may seek affiliation with other scientific societies in the American Association. Next year, however, the Society for the Scientific Study of Education, and probably also the conference of college instructors, will meet with the Department of Superintendence of the National Educational Association. One of the functions of such societies is to judge as a jury of peers the value of the discoveries and hypotheses made by its members. To the lack of any association of sufficient weight to perform this service is due in part the sufferance of educational fads and the paucity of serious investigations of the facts of school life. The impulse to research is dependent upon emulation, pride and practical wants, and the direction it takes depends still more upon social considerations. Publicity and esteem for intellectual work are among the agencies that assist progress in any field of thought. Organizations composed of experts in the study of education might also cooperate with other learned and scientific societies in important ways. The men now engaged in the promotion of knowledge through research and through the training of advanced students exert but slight influence in improving the teaching of the millions of children in the schools, and they will rarely be fit to do so directly. But a society formed of students of education who were their university associates might make use of both the knowledge and the reputation of these experts, and at the same time amend their recommendations to suit the actual conditions of school work. The recommendation of the British Association for the Advancement of Science has been thus used to support measures of reform in the teaching of geometry in Great Britain. In our own country such a formal organization of expert students of education might have led the National Educational Association to insist that the teaching of physiology be put beyond the reach of politics and one-sided enthusiasts.

BIOGRAPHIES OF EMINENT CHEMISTS.

IN our notice of the biography of the Swiss chemist Schönbein, in the POPULAR SCIENCE MONTHLY for April, we followed custom in giving him credit for discovering the passivity of iron, but the peculiar behavior of this metal induced by nitric acid had actually been observed forty-five years before by the English chemical manufacturer, James Keir. In his paper on the 'Dissolution of Metals in Acids,'

read to the Royal Society on May 20, 1790, Keir described quite fully many of the phenomena due to 'altered' iron, as he called it, and this property was afterwards known to many chemists; nevertheless, Schönbein first used the term *passivity*, and the discovery of the phenomena is commonly ascribed to him.

The 'Sketch of the Life of James Keir' is one of the rarest of the biographies of chemists, having been printed for private circulation, and edited by his grandson, James Keir Moilliet (London, 1868). Keir, who was born in 1735, was educated as a physician, but entered the army, and on retiring became a successful man of business, associated at one time with Boulton and Watt; he was an intimate friend of Erasmus Darwin and of Joseph Priestley, whose phlogistic views he shared in spite of the clear demonstrations of Lavoisier. In a letter to Darwin, dated 1790, Keir wrote: "I neither believe in phlogiston nor in oxygene, nor in any other of Lavoisier's metaphysical principles. . . . What I dislike in the anti-phlogistians is their pedantry and presumption; in the old system there is one assumed matter, whereas in Lavoisier's there are oxygene, hydrogene, calorique and carbone, all of which are imaginary, or at least hypothetical beings." Keir was a member of the social club known as the Lunar Society, which was founded in Birmingham in 1766, and lasted nearly forty years.

All that is known of this private society, its founders, its membership and its meetings is found in another privately printed volume, 'Scientific Correspondence of Joseph Priestley,' by Henry Carrington Bolton (New York, 1892); this contains ninety-seven letters of the eminent chemist who discovered oxygen, accompanied by historical and bibliographic notes. The book is illustrated by portraits of Priestley and of his friend Wedgewood, to whom many of the letters are addressed; they cover the period from 1780 to 1804, the last being written by Thomas Cooper to Dr. Benjamin Rush to announce the death of Priestley, which had occurred that morning (February 6). Some letters written in 1783 concerning Watts' experiments throw light on his share in the discovery of the composition of water. Priestley, as is well known, adhered throughout his life to the theory of phlogiston, and never accepted the doctrines of his contemporary Lavoisier. The life of this great French chemist was edited by Edouard Grimaux, in a handsome, well-illustrated volume (Paris, 1888). This contains besides the story of his grand discoveries, of his government positions and his domestic concerns, many official documents, supplying the historical proofs; the events associated with his arrest, imprisonment and unhappy and tragic end, are of painful interest.

Charles William Scheele, the poor apothecary of an obscure town in remote Sweden, made twenty-five prime discoveries, any one of which would have sufficed to make him famous; his 'Letters and Drawings,' edited by A. E. Nordenskiöld were published in a handsome octavo, illustrated with plates and fac-similes. The hundred and thirty-three letters extend from 1767 to 1781, and are addressed to Gahn, Bergman, Hjelm and others; the editor endeavors to prove from Scheele's manuscripts that he isolated oxygen more than a year earlier than Priestley. Books printed outside of Sweden were hardly accessible to Scheele. In 1777 he wrote to Gahn: "Priestley's book I have not yet seen. If it were in French I should like to read it. Here I am in great darkness as respects literature, a deprivation that is very unfortunate." Those seeking details of the life and labors of Scheele must consult this authoritative work, which appears in two editions, Swedish and German (Stockholm, 1892). Scheele wrote in both these languages

indifferently, but he used Latin and symbols taken from alchemical manuscripts to designate chemical substances.

THE CONDITIONS OF CHEMICAL ACTION.

It has long been known that the presence of water is necessary in order that many chemical reactions shall take place, and that substances which ordinarily unite with great violence have no action upon each other when thoroughly dried. It has even been found possible to distil phosphorus in an atmosphere of oxygen, provided that the phosphorus and oxygen are both perfectly free from any trace of the vapor of water. It has, however, been found by a number of experimenters that hydrogen and oxygen will unite with each other when heated, even if dried. This exception seemed to be due to the fact that when the two gases unite, water is formed, but theoretically the first particles of the gases could not unite unless a trace of water were present. This led Professor Brereton Baker, of Dulwich College, who has done much work along this line, to the idea that the gases used might not be perfectly pure. The oxygen and hydrogen for the experiment are generally formed by the electrolytic decomposition of dilute sulfuric acid or caustic potash. But several years ago Professor Morley, of Cleveland, pointed out that the gases from these sources contain traces of impurities. By electrolyzing highly purified barium hydroxid, Professor Baker was enabled to avoid previous errors and obtain absolutely pure gases. The mixed hydrogen and oxygen were thoroughly dried (over phosphorus pentoxid) and sealed in glass tubes. After ten days' drying the tubes were heated to 600 degrees Centigrade and remained perfectly unchanged, while companion tubes, similarly prepared, except as to the drying, exploded in every instance. In tubes which had been dried only two days, the hydrogen and oxygen united slowly to form water, but did not explode. In order to test the effect of higher temperatures, tubes were prepared with a silver spiral attached to platinum wires which were sealed into the glass. The spiral was heated until the silver melted, but no explosion took place and no hydrogen was formed. When, however, a platinum spiral was substituted the tubes did explode, probably owing to the catalytic action of the platinum. From the experiment with the silver wires it is evident that when perfectly dry, hydrogen and oxygen do not combine with each other, even at 1,000 degrees Centigrade, the melting point of silver.

The experiment with the partially dried gases seems to lend confirmation to the theory of Dr. Armstrong that without an electrolyte no chemical action is possible; for though water is but slowly formed, it is present in far greater quantity than is necessary to bring about the action, yet no explosion follows. It may be assumed here that the water formed by the union of very pure gases is itself very pure, and since pure water is not an electrolyte, this water should not cause an explosion of the gases.

THE PERIODICITY OF SOLAR PHENOMENA.

In the *Astronomische Nachrichten* (Numbers 3,723–24) F. Hahn has propounded a new theory to explain the periodicity of solar phenomena. The various theories, which have been advanced hitherto in explanation of the periodic phenomena which occur at the sun, have failed to take into account the so-called solar atmosphere, the light and heat absorbing envelope which surrounds the photosphere. The importance of this atmosphere, in connection with its influence on the radiant energy of the sun, has never been properly appreciated, although attention was called to it by Langley, who showed that the sun, if deprived

of its atmosphere, would radiate into space twice as much energy as at the present time. He also showed that an increase of 25 per cent. in the absorption by the solar envelope would lower the surface temperature of the earth by 100°F. Langley's attention was directed chiefly to the earth, and not to the reflex action on the sun itself, which such an atmosphere must exert. A decrease in the outside radiation of energy, caused by any change in the enclosing solar envelope, means an increase in the energy contained in the sun. It is reasonable to assume that changes in the absorptive power of the atmosphere must arise, and Mr. Hahn presents the query: What becomes of the energy which is prevented from escaping into space by the solar envelope? He endeavors to show that there may occur in the atmosphere changes sufficient to lead to alterations in the thermal conditions of the sun's mass and attempts to decide how far such changes may lead to the known variations in the phenomena at the surface of the sun. Astronomers are generally agreed in accepting the theory of Helmholtz, which accounts for the generation of the sun's heat by the contraction of its mass. This theory, while it explains the generation of heat in any star, does not in itself give information as to whether the amount of heat thus formed is just sufficient to balance that which is lost by radiation. As a fact, there are doubtless suns, as indicated by the spectroscope, which are increasing, and others which are decreasing, in temperature, and in the life of each sun there is, probably, a period of increasing, and later one of decreasing, temperature. Our sun is perhaps an example of those stars in which the heat lost by radiation is greater than that gained by contraction. With this assumption the layer of maximum incandescence and radiation will be shifted nearer and nearer toward the sun's center. The result will be that, due to the increased absorption of the denser envelope, the solar radiation will be decreased, which will tend to raise the temperature of the inner layers of the sun itself. By this overheating the vertical temperature-gradient will become so steep that mechanical equilibrium will be impossible. Although retarded by the powerful convection currents which prevail, disturbances will sooner or later ensue as a result of these strained conditions of the internal overheating, and solar outbursts will occur. Mr. Hahn then proceeds to an analytical demonstration.

The problem consists in determining the changes in the amount of the outside radiation, caused by increased or decreased absorption. The method is an application of the Bouguer-Lambert formula for the extinction of light and heat in an absorbing medium. Formulas have been derived for the energy of radiation from the upper limits of the atmosphere, for the changes in the radiating power, and for the frequency of eruptions and spots. The results thus obtained appear to be in close agreement with observation. The object of the article is to give an abstract of the main principles upon which is built a new solar theory. In a paper which is to appear in the *Annals* of the Edinburgh Royal Observatory the author will enter more in detail into the various applications of the theory to periodic phenomena at the sun's surface. This theory differs from the views generally accepted, in that it involves the assumption that an increase in the dynamical forces at the surface of the sun indicates a decrease in the heat and light radiation, but here also the author believes that his theory accords well with the facts of observation.

SCIENTIFIC ITEMS.

THE National Academy of Sciences held its annual stated session at Washington, beginning on April 15.—The spring meeting of the Council of the

American Association for the Advancement of Science was held on April 17. The annual meeting will be held at Pittsburgh, beginning on June 30.

THE portrait of Benjamin Franklin, executed by Gainsborough at the time of the signing of the Treaty of Paris, and lately given to the University of Pennsylvania by the class of 1852, has been hung in the University Library. —A memorial bronze tablet has been placed on the Albany (N. Y.) Academy in memory of Joseph Henry, stating that his experiments in electricity were made in that building while he was acting as professor of mathematics.

THE British National Physical Laboratory was formally opened on March 19. Sir William Huggins, president of the Royal Society, presided, and addresses were made by the Prince of Wales, Lord Rayleigh, Lord Kelvin and others.—Professor Emil v. Behring (Marburg) will give the amount of the Nobel prize recently awarded him ($40,000) to the Prussian State for the permanent endowment of the Institute of Experimental Therapeutics founded by him in the University of Marburg. The gift is to be devoted to the prosecution on a large scale of the researches on serum initiated by Professor Behring.—Lord Walsingham has given to the British Museum (Natural History) his collection of butterflies and moths. This collection of microlepidoptera contains over 200,000 specimens, and is probably the largest and most valuable in the world. It includes the Zellar, Hoffman, Christoph and other collections, and contains many type specimens. Lord Walsingham has himself published numerous monographs on the microlepidoptera.—An anonymous gift of $20,000, for the benefit of the Harvard College Observatory, has been received from a friend of the director, Professor Edward C. Pickering.

MR. ALEXANDER AGASSIZ and his party have returned to America, from their exploration of the Maldives. The principal work done was the sounding of the channels between the lagoons and the development of the plateau on which the atolls of the Maldives have been formed.—Dr. D. T. MacDougal has returned from Arizona and Sonora with an extensive collection of giant cacti and other large xerophytic plants, which are being installed in the horticultural houses of the New York Botanical Garden.